APPENDIX XII

SOME METHODOLOGICAL PROBLEMS IN THE ECONOMIC APPRAISAL OF INCREMENTS OF IRRIGATION WATER, SEVIER VALLEY, UTAH

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FOREWORD

In 1960, the U. S. Department of Agriculture and the State of Utah began a cooperative study of land and water resource use and possibilities for development in the Sevier River Basin. Three services (Economic Research Service, Forest Service, and Soil Conservation Service) within the Department of Agriculture have participated actively in the study. General guidance for the Sevier River Basin Investigation has been provided by the U. S. Department of Agriculture Field Advisory Committee. Dr. Clyde E. Stewart, ERS representative has supervised the economic aspects of the USDA investigations. Coordination between State and Federal agencies has been provided by the Utah State Engineer.

The purpose of this report is to make available, to anyone concerned with water resource development, the results of work related to basic water use and crop-yield relationships derived from farm survey data. It is recognized that this work is only an initial effort along this line. Research results suggest that further cooperative study between agronomists, economists, and engineers should help to further define the factors that affect crop yields at the farm level.

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SOME METHODOLOGICAL PROBLEMS IN THE ECONOMIC APPRAISAL OF INCREMENTS OF IRRIGATION WATER, SEVIER VALLEY, UTAH

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INTRODUCTION

Problem

The role of the economist in water resource development is to evaluate the relationship between man and his resource environment. To do this it is necessary that he know the how, where, and when of resource use in numerical terms. This requires an understanding of the physical, biological, and technological relationships relevant to resource use. In addition, it requires the identification and specification of variables pertaining to the problem, and the relationships that exist between variables. With this understanding it is possible to work out an economic solution to resource use problems.

Productivity may be defined in either physical and/or economic terms. Physical productivity is the yield in product. Economic productivity is the monetary income produced. Net income is an essential economic measure of productivity in determining the most efficient use of resources. Knowledge of physical productivity is necessary to determine economic productivity.

Economists have encountered difficulties in determining the value of irrigation water. These problems have arisen because of inadequate data and procedures to analyze complex relationships that affect crop yields at the farm level. Data necessary for the establishment of water-yield relationships are available either from experimental studies or farm surveys. Current data on usable experimental studies are limited.

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In recent years, agronomists have concentrated their efforts on establishing yield-water relationships which are independent of soils and gross quantities of irrigation water. Problems arise in interpreting and adapting experimental data to fit study conditions. In most cases experimental studies are not broad enough in scope to fit the range of project conditions.

A basic need of the economic analysis of irrigation water use is that the physical and economic resource alternatives be internally consistent and representative of the study area. Economists have traditionally used the farm survey method to obtain data on farm characteristics, farm inventories (livestock, machinery, and buildings), crop production practices, crop yields, labor inputs, etc. This approach enables economists to relate directly their analysis to project conditions. In most cases survey data are supplemented with data from secondary sources to complete study needs.

A need exists to identify the different factors that affect water-yield relationships at the farm level. A method to evaluate the individual and combined effects of different factors on water-yield relationships is needed. Once these factors have been identified and their effects upon water use and crop yields defined, much progress will have been made toward the establishment of the physical and economic productivity for irrigation water. The use of survey data will have been broadened and progress made toward tying together physical and economic data for water resource planning.

Background for Study

In 1960, the U. S. Department of Agriculture and the State of Utah began a cooperative study to examine the problems of land and water resource use and possibilities for development in the Sevier River Basin. Three Services (Soil Conservation Service, Economic Research Service, and Forest Service) within the Department of Agriculture have participated actively in the study.

The purpose of the economics portion of the Sevier River Basin study is to appraise present and potential agricultural uses of water and related land resources, and to identify profit-maximizing farm organizations under various distributions of resources among farms and areas.

Difficulties have been encountered in establishing water-yield relationships in the Sevier River Basin. The problems center around the many variable factors that influence water use and crop yields. It was decided that the selection of one crop for concentrated study would add to the reliability of the overall study and help identify the variables that influence water-yield relationships at the farm level. Alfalfa in the Sevier Valley was selected for special study.

Study Objectives

The primary objective of this study was to establish the physical productivity of irrigation water applied to alfalfa grown in the Sevier Valley using farm survey data. The secondary objectives were to point out some of the analytical difficulties in establishing the incremental productivity of water used to irrigate alfalfa and identify the variables that affect the water-yield relationships at the farm level.

Results of the study will demonstrate the feasibility of using farm survey data to establish water-yield relationships. Demonstrating this would not only broaden the use of survey data, but would also help improve the reliability and significance of the economic evaluation of irrigation water by tying together the physical and economic analysis of water use to a common data source. The study will indicate the data needed by economists to evaluate irrigation water and point up some problems in obtaining these data.

Method of Study

Data were collected from farmers by personal interviews. The questionnaire contained detailed information on one randomly selected alfalfa field on each survey farm. The survey included questions on size of field, rotation, source and amount of irrigation water, irrigation practices, fertilizer use, crop yields by cuttings, size and type of equipment, machinery inputs, labor inputs, and management practices. The date each operation was performed was also obtained. Data were collected during the summer of 1963 for crop year 1962. Soils information on each field was obtained from the Soil Conservation Service, U. S. Department of Agriculture.

As a basis for sampling, a list of all farm operations in the area was compiled. Farmers were grouped by type of farm, size of farm, and cropland acreage. The population, from which a sample was surveyed, included 1,005 of the 1,067 farmers in the area. Classes of farms not included in the survey population were institutional farms, idle farms, farms in the soil bank, and farms about which no information could be obtained.

Records were obtained from 103 operators selected from a stratified random sample of the survey population. Of the 103 records, 27 were not included in the analysis because of incomplete data. Lack of information on amount of irrigation water used was the primary reason for discarding records.

Variable factors that affect alfalfa yield were identified from experimental research on alfalfa production. Individual factors were grouped into either physical, nonwater management or water management groups for study purposes. All factors were evaluated individually and as a group to determine their effect on alfalfa yield. Several numerical measures of water use were developed and tested in the study.

A model building program was employed to identify the functional relationships between the dependent and independent variables. The program is designed to show numerically the main effects and two-way interaction effects of every combination of independent variables. In general the procedure divides the observations for each variable into high, middle, and low groups and gives the mean yield for each group. The second step combines two variables and sorts the observations into every combination of the three groups for each of the variables. Mean yields for the resulting nine groups can be plotted graphically to observe the main and interaction effects of the two variables. The program enables selection of the significant variables and identification of functional relationship and interactions between variables.

A stepwise multiple-regression program was used to further eliminate variables not important in effect on the dependent variable and to measure the influence of all the independent variables on the dependent variable.

The stepwise program successively eliminates the least important variable remaining in the program and measures the change in the coefficient of multiple determination due to the eliminated variable. The sum of information attributed to individual variables is equal to the coefficient of multiple determination. The difference between their sum and 1.00 is the unexplained variation. In addition, simple correlation coefficients between all combination of variables were obtained to indicate high correlations and independence between explanatory variables.

Several models were constructed and a multiple-regression technique used to evaluate the relationship of each model to alfalfa yields. The variables were classified into three groups for model evaluation purposes. Various combinations of groups were evaluated in addition to groupings of variables which represented different situations and techniques used to measure water-yield relationships in other studies.

Characteristics of the Study Area

Sevier Valley lies in south-central Utah. The study area extends from the town of Sevier on the south to Fayette on the north. The major cities in the area are Monroe, Richfield, Salina, and Gunnison. Approximately 75,000 acres of land are irrigated within the area. The proportions of irrigated crops are alfalfa, 44,380 acres; small grains, 16,830 acres; corn for silage, 4,980 acres; sugar beets, 4,680; and pasture, 4,120 acres (22).

Sevier Valley is relatively flat with lands sloping from both sides of the valley to Sevier River which runs from south to the north through the floor of the valley. Soils are relatively homogeneous and generally range from medium to moderately fine in texture. Soils of any one texture

tend to be located in blocks and soils on individual farms are usually of one type.

Irrigation water comes from the San Pitch and Sevier Rivers, tributary streams, springs, and storage in Piute, Nine Mile, and Gunnison Reservoirs. The average annual water resource of the area has been estimated to be 446,400 acre-feet of which 196,490 acre-feet are consumptively used by irrigated crops and 50,560 acre-feet consumptively used on nonirrigated meadows and saltgrass areas (22). Irrigation water supplies are short during the months of July, August, and September.

The average size of farm in the area was 246 acres in 1962. Irrigated cropland averaged 84 acres per farm and 13 of these acres were idle. Farmers owned 62 percent of the land they operated and rented the remaining 38 percent (26).

REVIEW OF LITERATURE

Prior to this study no results have been published of attempts to identify the factors that affect the water-yield relationship for alfalfa in the Sevier Valley using farm survey data. In the early part of the century Harris, Widstoe, Merrill, and Pittman (6, 15, 25) published results of experimental work at Logan on yield responses of alfalfa to different methods of irrigation, rotations, and fertilizer use. Tovey (19) has done some recent experimental work at Reno on the consumptive use of moisture and alfalfa yields grown in the presence of static water tables. Several studies have been made by Experiment Stations on the effects of fertilizer use on alfalfa yields and water-use efficiencies (4, 14, 23). Available literature on history of development, adaptability to climate, effects of pests, and rotations on alfalfa production were reviewed (1, 11). Other relevant studies have been grouped for reference purposes.

Economic Studies

A review of literature failed to find any studies which used farm survey data to establish a water-yield relationship for alfalfa. Both experimental and survey data were used in establishing production functions for field corn and bush beans in Oregon (12). In this study the dependent variable was gross return per acre and the independent variable was irrigation water applied.

Ellis (5) used a correlation analysis with average yields and average water inputs over a series of years to establish a production function

in his study. A "dummy" variable was used to measure the influence of other factors (other than water) on yields.

Moore (13) maintains that there is a production function for each irrigation cycle and that total output can only be estimated by taking into account all irrigation cycles. This approach takes into account not only the physiological relationships within each irrigation cycle but also intraseasonal variations in the supply of water.

A common practice, used by economists, in water resource evaluation is the "with" and "without" project approach (21). This approach measures the difference in agricultural production resulting from project water and facilities and increased use of associated farm resources. The value of increased production less the cost of increased resource inputs plus any reduction in associated farm costs with the project, are defined as direct agricultural benefits to the project. Different resource combinations are delineated and taken into account in the analysis, but these studies usually do not consider possible profitable adjustments between crops as alternatives in their analysis.

In addition to the above publications related to the area of study, the author read many articles on production functions of various kinds. Heady and Dillon's book (7) on agricultural production functions was very helpful in this study. Hurst and Pedersen's publication (8) on alfalfa seed was helpful on statistical and procedural methods employed in this study.

Soils and Moisture Studies

The total water requirement for a crop is the sum of the daily requirements for every day of the growing season. Weather conditions determine more than anything else how much water will be required for growth. The amount of water used by a plant or the transpiration rate varies considerably during the year. The rate of growth also varies within the growing season (19). Monthly consumptive-use rate or evapotranspiration rates are accepted measures of potential water use (3).

Water is retained in the soil in varying amounts. The type of soil limits the amount that can be stored. In general, inches of available moisture that can be stored in a foot of sand range from 0.25 to 0.75; loamy sand, 0.75 to 1.25; sandy loam, 1.00 to 1.50; fine sandy loams, 1.50 to 2.00; clay loams, 1.75 to 2.25; and clays, 2.00 to 3.00 (3).

Plants cannot remove all the water retained in a soil root zone. Water is held by forces in the soil and plants must exert forces greater than those in the soil to withdraw the water. The amount of force with which water is held in the soil is called soil moisture tension. Soil moisture tensions vary from .5 atmosphere at field capacity to about 15 atmospheres of tension at the wilting point (18). The amount of water held in the soil between field capacity and the wilting point is called available moisture. Estimates have been made that maximum production can be obtained if not more than 50 percent of the available water is removed between irrigations. At least 75 percent of available moisture can be removed during the mature stages of growth without detrimental results (9).

Observations in Utah indicate that the amount of water removed from the soil by alfalfa did not vary greatly between 1 and 8 atmospheres. When

the tensions approached 8 atmospheres before irrigation, yields were reduced (18).

Research has shown that alfalfa yields are affected by soil texture without regard to water (19). Martin (11) indicates that alfalfa is best adapted to deep loam soils with porous subsoils and good drainage.

Kramer (10) reported that attempts have been made to grow plants at various moisture contents between field capacity and the permanent wilting point. They have been unsuccessful because it is impossible to half wet a soil and it appears practicably impossible to permanently maintain any intermediate moisture contents. If insufficient water is added to the root zone to wet the soil to field capacity, part of it will be wetted to field capacity and the remainder will remain unaffected.

THEORETICAL AND ANALYTICAL FRAMEWORK

Production Functions[1]

A production function shows the relationship between the inputs of resources and the resulting yield of product. It simply means that output is a function of the amount of inputs. The term input-output relationship is also used at times by economists as a counterpart of the production function.

A production function for alfalfa shows the relationship between all inputs and the resulting yield of alfalfa. The production of alfalfa is the result of many factors such as land, seed, water, labor, fertilizer, machinery, and management. Production of alfalfa can never be the result of a single factor alone. The variation in the yield of alfalfa due to a variable input can be determined if all the inputs required for the growth of a crop are held constant, except one variable input. This procedure is commonly used by physical scientists and economists when determining the variation due to a single input. When any one of the inputs are held constant the resulting production function is termed a short-run production function. If all inputs are variable the resulting curve is called a long-run production function.

Short-run production function

Figure 1 shows the theoretical short-run production function for alfalfa and irrigation water. The curve Yp shows the yield of alfalfa

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[1]The information presented in this section on production functions is essentially a summary of points found in Heady and Dillon's book (7) pp. 1-217.

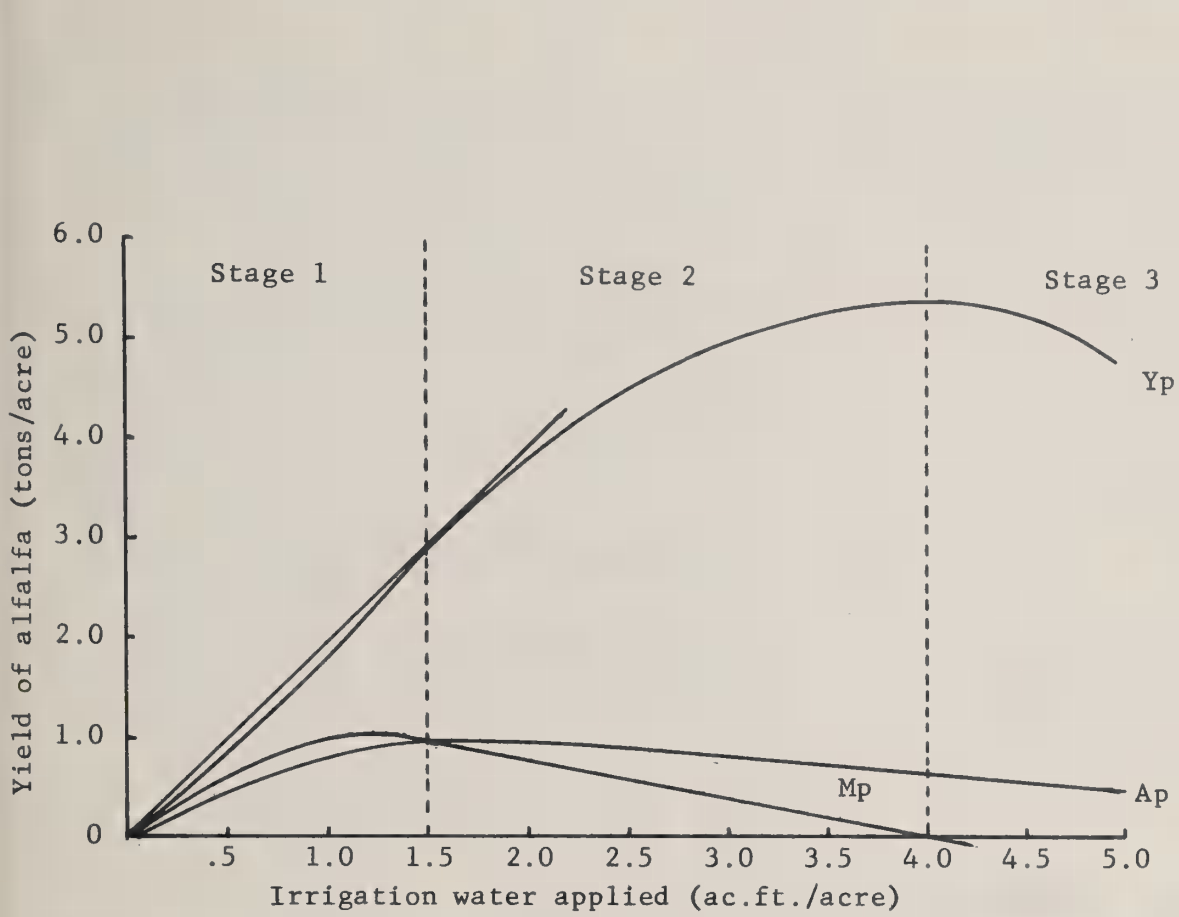


Figure 1. Illustrative short-run physical production function showing relationship between alfalfa yield and irrigation water applied.

on an acre of land with varying quantities of irrigation water. Mp represents the increased production with the addition of more units of water and Ap shows the yield per unit of irrigation water.

The stages of economic production are also illustrated in Figure 1. These physical relationships and stages of production have important economic implications. The area of rational use of inputs is defined by the stages of production. Any level of resource use falling in stages 1 and 3 is irrational. Stage 1 is uneconomical because the use of one additional unit of the variable input will increase the average return for all inputs. Stage 3 is uneconomical because the use of additional units of inputs will decrease total production. The most economical point of resource use within stage 2 can only be determined after prices for inputs and outputs are known.

Given prices for inputs and output, problems of efficiency and allocation can be solved. An input is used efficiently if the marginal unit cost of the input is equated with the marginal value product of the input. In the case of several uses of crops on which water could be used, the proper allocation of water can be determined be equating the marginal value products of water on all crops.

Production functions and study procedures

Sundquist and Robertson (17) report that the yield of a particular crop (y) in a given time period (t) is the gross product of energy, genetics, and nutrients. This relationship can be specified as follows:

$$Y_t = f \text{ (energy, genetics, nutrients)}$$

They also state that experience will verify that the numerous components of these categories that affect yields are interdependent and

interact with each other. The ways in which these growth factor groups can be combined to affect yields are infinite in number.

In general, scientists working the production functions must recognize that they are only dealing with a portion of the total variables that affect crop yields. Therefore, statistical representations of crop-growth relationships do not contain all the variables that affect crop yields and relationships derived only apply to specific time periods.

Several techniques can be employed to obtain useful measures of the effects of varying quantities of the desired variable factors. Some factors can be held constant by experimental planning and data collection methods, while other factors can be allowed to vary from one time period to another to obtain the probable distribution of expected responses.

The degree to which these techniques can be practiced is determined to a large degree by the source of data. Data are available from either experimental or nonexperimental sources. Experimental data are characterized by the fact that data are generated under the researcher's control. He can decide which variables will be controlled at different levels as well as combinations of variables at different levels. Unlike experimental data, nonexperimental data are originated independent of the researcher. The only control the researcher has is by method of data collection. From the researcher's point of view, the ex post control on nonexperimental data is not as desirable as ex ante control exercised on experimental data. Due to lack of control by the researcher, errors in the estimates of explanatory variables are to be expected when the respondents are asked to recall past actions. These conditions are not meant to imply that data collection should always be based on experimentation. In many cases experimental

procedures are either mechanically infeasible or not worthwhile in terms of the cost and benefits relative to nonexperimental data collection. Problems also arise, particularly in resource development studies, that do not allow necessary time to design and carry out experimental studies over long time periods. Generally, project study periods are relatively short in duration. It can also be argued that experimental conditions are not representative of the conditions under which farmers operate. By exercising ex post control, a researcher can greatly increase the value of real-world data and may in some instances approach comparable experimental data.

The determination of a production function can be formalized in the following equation:

$$Y = f\ (X_1, X_2, \ldots, X_k)$$

This equation assumes that all relevant variables are represented by X_1 to X_k. Under real-world conditions it is most likely that only a portion of the total variables are represented. Under these conditions the equation would take the following form:

$$Y = f\ (X_1, X_2, \ldots, X_g) + e$$

the e represents the error due to the omission of inputs $X_g + 1$ to X_k, assuming no errors in observations on X_1 to X_g. Some of the input factors $X_g + 1$ to X_k will be fixed and some will be variable. If it is known which inputs are variable and which are fixed, the equation can be shown as follows:

$$Y = f\ (X_1, X_2, \ldots X_g/X_g + 1, \ldots X_h//X_h + 1 \ldots, X_k)$$

This would indicate X_1 to X_g are variable and $X_g + 1$ to X_h are fixed at a known or unknown level and $X_h + 1$ to X_k are variable and unobserved. The value of the derived production function can be judged by the importance of

factors $X_h + 1$ to X_k and factors $X_g + 1$ to X_h that are held fixed.

Data used in establishing a production function should meet several different criteria. First, the data should be relevant to the production function being estimated. Problems arise in obtaining observations in sufficient numbers for all levels and all input factors. The scale of measure of different variables sometimes becomes a problem. Secondly, care is necessary in using survey data to avoid hybrid functions[1] by exercising ex post control of unrecorded variable factors. The extent to which fitted hybrid functions misinterpret the production surface depends upon the importance of the unobserved variable factors to the observed factors. Thirdly, the observations should be scattered over the production surface to avoid problems of multicolinearity. These problems are associated with using inputs in fixed proportions. This problem can be avoided by purposive rather than random sampling.

Statistical Tests

The adequacy of a production function can be judged by applying known logic about the production relationships and statistical tests. The logic relating to physical relationships is applied early in the study planning stages. Statistical tests for adequacy are applied in the model building and evaluation stages.

Statistical tests used in the study were simple correlations between dependent and independent variables and between independent variables, the coefficient of multiple determination, and an F test of the regression mean squares.

[1]A hybrid production function is one in which a fitted function incorporates points lying on a number of different production surfaces instead of the intended single production surface.

STUDY VARIABLES

The purpose of this section is to describe the source, form, and method used to establish study variables. Relationships that form a basis for study assumptions and definitions are also included. The availability of data and basic water-yield relationships were both considered in the selection of variables. Several numerical measures of irrigation water use were developed and included in the study to test their adequacy as indicators of irrigation water use within the study area.

Alfalfa Yield (Y)

Total alfalfa yield was the dependent variable used in the analysis. Total alfalfa yield was selected for use as the only dependent variable because analysis indicated that there was a strong correlation between yield per cutting and total yield (Table 1). Yields per cutting were the highest for first cutting, second cutting, and then third cutting, in that order. Observations by cuttings were grouped into high, middle, and low yield levels and compared to total yield. Data indicate a definite relationship between yield levels per cutting and total yield levels.

Physical Factors

Soil Surface Texture (T)

Soil surface texture was homogeneous within large blocks of land and usually within the confines of any one farm. Moderately heavy soils accounted for 55 percent of the survey samples and medium textured soils

Table 1. Average alfalfa yield by high, medium, and low groups for yield by cutting and total yield on sample fields, Sevier Valley, 1962

Group	Obser-vations	Cutting yield	Range in cutting yield	Total yield	Range in total yield
	Number	Tons/ac.	Tons/ac.	Tons/ac.	Tons/ac.
1st cutting[a]					
Low	24	1.4	0.5-1.75	3.3	1.0-5.0
Medium	25	2.0	2.0-2.25	4.3	3.0-5.5
High	27	2.6	2.5-3.25	5.3	4.0-6.25
2nd cutting[b]					
Low	25	1.0	0.5-1.25	3.1	1.0-5.0
Medium	32	1.5	1.5	4.6	4.0-5.0
High	19	2.0	1.75-2.5	5.4	4.0-6.25
3rd cutting[c]					
Low	30	0.4	0.0-0.75	3.3	1.0-5.0
Medium	39	1.0	1.0	4.9	3.5-6.25
High	7	1.5	1.5	5.5	5.0-6.0
Total yield[d]					
Low	21	--	--	2.9	1.0-3.75
Medium	20	--	--	4.1	4.0-4.5
High	35	--	--	5.3	5.0-6.25

[a]Simple correlation between first cutting and total yield 0.86.

[b]Simple correlation between second cutting and total yield 0.86.

[c]Simple correlation between third cutting and total yield 0.79.

[d]Average yields by cuttings do not add up to total yield because observations were sorted by cuttings and for total yield.

41 percent (Table 2). Other soils included 4 percent of the observations.

Table 2. Number of observations by soil surface texture classes, Sevier Valley, 1962

Soil surface texture	Observations
	Number
Heavy	1
Moderately heavy	42
Medium	38
Light	2

The available water-holding capacity of soils varies with their texture. Available moisture is the difference in moisture content of soil between field capacity and the permanent wilting point. The figures shown in Table 3 indicate the available moisture-holding capacities used in this study. A 6-foot alfalfa root zone was assumed to determine the total available water. These figures correspond with data reported by Stanberry (16) on alfalfa root zone and Hansen and Israelson (9) on available water for different soil textures. If an inhibiting layer was shown in the soils data, the root zone was adjusted to correspond with the depth to the inhibiting layer. The majority of the soils in the area are deep. Soil depth to an inhibiting layer was over 36 inches in 92 percent of the observations.

Table 3. Available moisture-holding capacity of different soils assuming a 6-foot alfalfa root zone

Soil texture	Available moisture per foot of soil	Total available moisture for alfalfa
	Inches	Inches
Heavy	2.2	13.2
Moderately heavy	2.0	12.0
Medium	1.7	10.2
Light	1.4	8.8

Subsoil Permeability (P)

Forty-six percent of the observations had a slowly permeable subsoil and 50 percent had a moderately permeable subsoil (Table 4). Soil surface texture and subsoil permeability were closely associated. Of those soils with a moderately heavy surface texture, 76 percent had a slowly permeable subsoil and 24 percent had a moderately permeable subsoil. Eighty-four percent of the medium textured soils also had moderately permeable subsoil.

Table 4. Number of observations by subsoil permeability classes, Sevier Valley, 1962

Subsoil permeability rate	Observations
Very slowly permeable	1
Slowly permeable	35
Moderately permeable	38
Rapidly permeable	2

Slope (S)

Slopes are low in the area (Table 5). Only 13 percent of sample fields had slopes of 3 percent or over. Sixty-two percent of the fields had slopes of 1 percent or less.

Table 5. Number of observations by slope groups, Sevier Valley, 1962

Slope group	Observations
Percent	Number
1 or less	47
2	19
3	7
4 or more	3

Nonwater Management Practices

Fertilizer Use (F)

Fertilizer use was common practice in the area (Table 6). Forty-one percent of the fields were fertilized in 1962. The amount of available phosphorus applied in 1962 was used in the analysis. In cases where manure was applied, credit was given on the basis of available phosphorus in the manure.

Table 6. Fertilizer use on alfalfa by classes, Sevier Valley, 1962

Fertilizer use Available P_2O_5/ac.	Observations Number
None	45
50 lbs. or less	14
More than 50 lbs.	17

Total Growing Days (G)

The growing period used in the study was the number of days between May 1 and the date of the last cutting of hay. All water-use variables correspond with this period. The maximum period considered was 153 days or from May 1 to September 30. The growing period was figured for each individual observation. The growing period varied from a low of 81 days to a high of 153 days. The average growing period was 133 days.

Table 7. Length of growing period for alfalfa by classes, Sevier Valley, 1962

Group	Observations	Average growing period	Range in growing period
	Number	Number of days	Number of days
115 or less	7	96.7	81-111
116-125	12	123.2	123-125
126-135	13	131.2	127-132
136-145	30	137.7	137-142
145 or more	14	150.2	146-153

Years in Rotation (A)

Alfalfa was left in the rotation from 3 to 20 years (Table 8). Most farmers leave it in the rotation for 4 to 6 years. The age of alfalfa stand on each field was not available and average number of years in rotation was used as an alternative to the age of the stand.

Table 8. Number of years alfalfa left in rotation, Sevier Valley, 1962

Alfalfa rotation	Observations
Years	Number
3	2
4	12
5	28
6	11
7	6
8	8
9	2
10	5
11 or more	2

Water Management Practices

Number of Irrigations (I)

The number of irrigations applied to alfalfa ranged from 2 to 11. The average number of irrigations on alfalfa was 4.5. The number of irrigations includes those applied prior to the start of the growing season. The distribution of irrigations by number of irrigations is shown in Table 9.

Table 9. Number of irrigations applied on alfalfa, Sevier Valley, 1962

Irrigations applied	Observations
Number	Number
2	5
3	18
4	18
5	13
6	15
7	5
8 or more	2

Date of First Irrigation (D)

The date of the first irrigation on alfalfa varied from March 1 to June 5 (Table 10). The average starting date was April 28.

Table 10. Date of first irrigation on alfalfa, Sevier Valley, 1962

Group	Observation	Average time of first irrigation	Range in starting time
Date	Number	Date	Date
3/31 or before	4	3/12	3/1-3/25
4/1-4/15	21	4/10	4/1-4/15
4/16-4/30	10	4/24	4/20-4/30
5/1-5/15	33	5/10	5/1-5/15
5/16-5/31	7	5/22	5/17-5/25
6/1 or after	1	6/5	6/5

Nongrowing Season Water (N)

Nongrowing season water is defined as irrigation water applied prior to May 1. The amount of nongrowing season irrigation water applied varied from zero to 4.6 acre-feet per acre (Table 11). Farmers applied an average of .4 acre-feet per acre. Fifty-four percent of the farmers did not irrigate prior to May 1.

Table 11. Irrigation water applied to alfalfa before the start of the growing season, Sevier Valley, 1962

Group	Observations	Average water applied	Range
Acre-feet per acre	Number	Acre-feet per acre	Acre-feet per acre
0.00	41	0.0	0.0
0.01-0.50	9	0.42	0.30-0.50
0.51-0.75	8	0.63	0.53-0.75
0.76-1.00	11	0.88	0.76-1.00
1.01-1.25	3	1.10	1.08-1.13
1.26 or more	4	2.45	1.48-4.58

Water in Growing Season (W)

Water in the growing season is defined as any irrigation applied between May 1 and the date of the last cutting of hay. The amount of irrigation applied varied from 1.44 acre-feet to 9.52 acre-feet per acre. Farmers applied an average of 2.4 acre-feet per acre during the growing season. The distribution of irrigation water use is shown in Table 12. Water-use figures are for irrigation water delivered to the field.

Table 12. Irrigation water applied to alfalfa during the growing season, Sevier Valley, 1962

Group	Observations	Average water applied	Range
Acre-feet per acre	Number	Acre-feet per acre	Acre-feet per acre
1.00 or less	5	0.77	0.44-0.87
1.01-1.50	15	1.33	1.02-1.50
1.51-2.00	15	1.73	1.58-1.95
2.01-2.50	16	2.28	2.03-2.50
2.51-3.00	10	2.80	2.58-3.00
3.01-3.50	6	3.29	3.02-3.50
3.51-4.00	3	3.99	3.99-4.00
4.01-4.50	2	4.35	4.19-4.50
4.51 or more	4	6.67	5.28-9.52

Consumptive Use in the Growing Season (C)

Consumptive use in the growing season is defined as the amount of evapotranspiration between May 1 and the date of the last cutting of hay. The consumptive-use period corresponds with the growing season for each individual observation. Consumptive use was calculated by taking into consideration the number and dates of irrigations, available water-holding capacity of the soil, monthly potential consumptive-use rates, monthly precipitation, and availability of soil moisture to alfalfa. The consumptive use for each observation is the sum of the monthly potential consumptive-use rates for the days within the growing season that soil moisture was available to alfalfa. Seventy-five percent of the available moisture

in the soil was assumed to be available to alfalfa. Available moisture values used in the study are shown in Table 13. Table 14 shows the potential consumptive use, precipitation, and irrigation needs for the study area.

Table 13. Assumed moisture available for plant growth between irrigations, Sevier Valley, 1962

Soil texture	Total available moisture in alfalfa root zone	Moisture available to alfalfa for consumptive use
	Inches	Inches
Heavy	13.2	9.9
Moderately heavy	12.0	9.0
Medium	10.2	7.65
Light	8.8	6.6

Consumptive use of moisture during the growing season varied from 11.0 inches to 27.9 inches per acre. The average in the area was 23.4 inches. The distribution of consumptive use of moisture is shown in Table 15.

Table 14. Potential consumptive-use rates, precipitation, and irrigation needs for alfalfa, Sevier Valley, 1962

Period	Potential consumptive use	Precipi-tation	Accumulated soil moisture storage	Irrigation needs
	Inches	Inches	Inches	Inches
Jan.	0.21	0.74	0.96	
Feb.	0.40	0.81	1.37	
Mar.	1.08	0.89	1.18	
Apr.	2.11	0.83	--	0.10
May	3.90	0.84	--	3.06
June	5.87	0.62	--	5.25
July	7.47	0.73	--	6.74
Aug.	6.53	0.73	--	5.80
Sept.	3.93	0.50	--	3.43
Oct.	2.06	0.77	--	1.29
Nov.	0.65	0.64	--	--
Dec.	0.27	0.71	0.43	--
Year	34.48	8.81	--	25.67

Source: U.S. Department of Agriculture, Sevier River Planning Party.

Table 15. Consumptive use of moisture by alfalfa during the growing season, Sevier Valley, 1962

Group	Observations	Average consumptive use	Range in consumptive use
Inches/acre	Number	Inches/acre	Inches/acre
16 or less	5	13.8	11.0-15.8
16.1-18.0	1	17.0	17.0
18.1-20.0	7	19.5	18.1-19.9
20.1-22.0	6	21.0	20.1-22.0
22.1-24.0	16	23.4	22.3-24.0
24.1-26.0	29	25.2	24.1-25.8
26.1 or more	12	27.2	26.1-27.9

Optimum Moisture Days (O)

Optimum moisture days are defined as the number of days in the growing season that soil moisture was available to alfalfa above the 50 percent level. Optimum moisture days were calculated by summing the number of days in the growing season that the available moisture level in the soil was above 50 percent. This measure assumes that maximum yields can be obtained if the available moisture in the soil is not drawn below 50 percent.

The number of optimum moisture days varied from 42 to 152 in the growing season. The average number of optimum moisture days in the growing season was 103. Table 16 shows the distribution of days within the growing season that optimum moisture was available to alfalfa for growth.

Table 16. Optimum moisture days for alfalfa within the growing season, Sevier Valley, 1962

Group	Observations	Average optimum moisture days	Range in optimum moisture days
No. of days	Number	Number	Number
60 or less	5	50.6	42-59
61-80	6	68.3	64-73
81-100	23	91.7	82-100
101-120	21	109.2	101-116
121-140	19	128.0	121-140
140 or more	2	149.5	147-152

Water-Use Considerations

Water Application Efficiency

It was assumed in the study that the alfalfa root zone would be filled to field capacity on each irrigation before any irrigation water was lost to surface runoff or to deep percolation. Even if enough water were not applied to fill the soil to field capacity, credit was given for 100 percent storage of water applied in the root zone. The level of available moisture at the time of irrigation was taken into consideration in determining water needs to bring the soil to field capacity. One day after each irrigation was allowed for the soil to drain to field capacity. Precipitation was assumed to be 100 percent effective and distributed over the month. Consumptive-use rates were varied by monthly periods. Consumptive use was shown only if moisture was available to the alfalfa plants.

Farmers applied an average of 33.9 inches of irrigation water and 20.3 inches of this water was consumptively used during the growing season. The average water application efficiency was 60 percent. When consideration is given to the 3.1 inches of precipitation during the growing period, the average water-use efficiency was 63 percent.

Potential consumptive use during the growing period was 25.1 inches, while actual consumptive use was 23.4 inches of moisture. These quantities indicate that farmers were 7 percent short of water during the growing period.

Yield-Consumptive-Use Ratio

Consumptive-use and alfalfa yield data indicate that there is a significant relationship between the alfalfa yield level and the alfalfa yield-consumptive-use ratio. Efficient use of irrigation is associated with higher alfalfa yield levels. Figure 2 shows the yield-consumptive ratio for all observations. Data indicate that the amount of moisture consumptively used to produce a ton of alfalfa varies from 3.2 inches to 11.0 inches. The mean moisture required was 5.79 inches per ton of alfalfa produced.

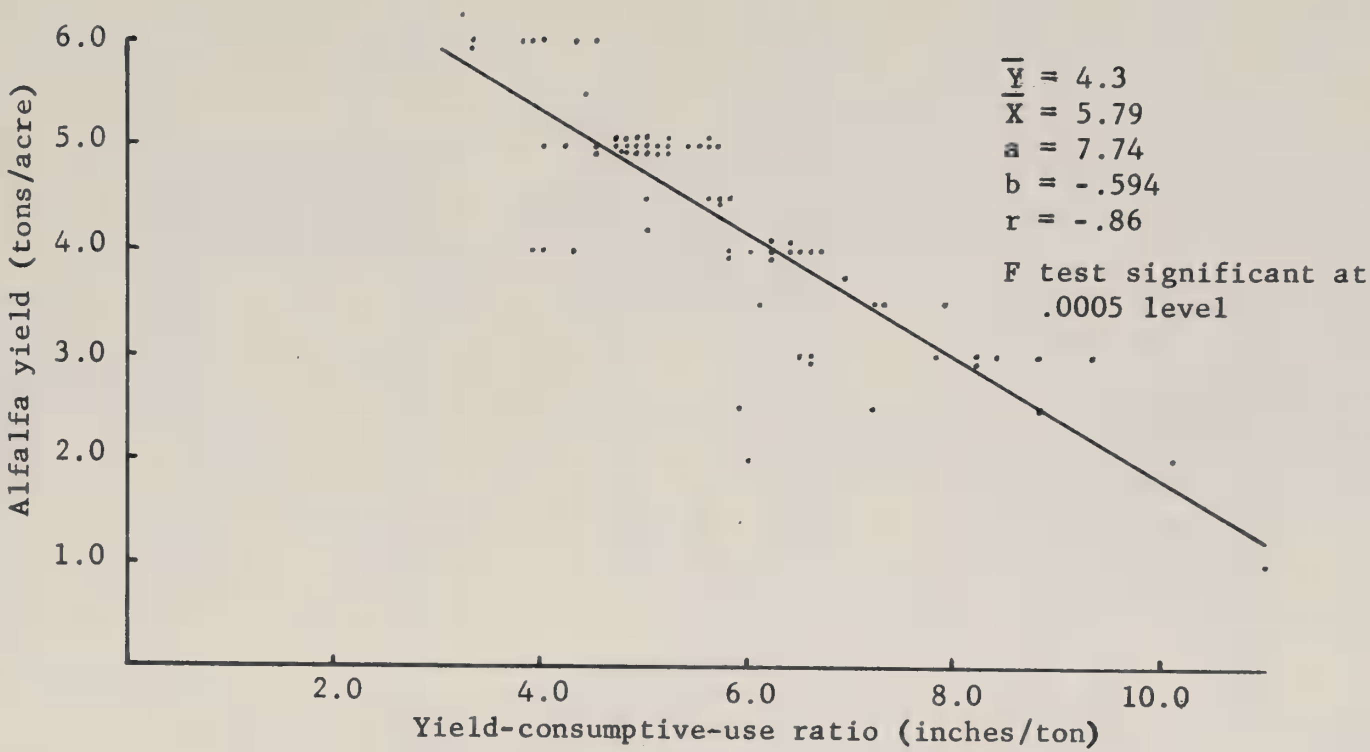


Figure 2. Relationship of alfalfa yield to yield-consumptive-use ratio, Sevier Valley, 1962.

ANALYSIS AND PRESENTATION OF DATA

Functional Relationships

Three methods were employed to identify functional relationships between independent variables and alfalfa yield. First, a linear regression and scatter diagram analysis were used to establish the over-all relationship of independent variables to alfalfa yield. Secondly, a model building program was employed to identify main effects and the two-way interaction effects of combinations of variables on alfalfa yields. Thirdly, simple correlation and a stepwise multiple regression program were used to test the correction and the contribution of information provided by individual variables to explain the variation in alfalfa yield.

Regression Analysis

Regression analysis was used to determine the over-all relationship of individual variables to alfalfa yield. All variables were determined to be nonlinear when compared to alfalfa yield. Figures 3 to 5 illustrate the results for selected water management variables. Results indicate that in general terms fertilizer use, total growing days, number of irrigations, water applied in the growing season, optimum moisture days, and consumptive use of moisture had an increasing effect on alfalfa yield as units of inputs were increased. Alfalfa yield decreased at lighter soil surface textures, as subsoil permeability rate increased and as years in rotation were increased. Slope, date of first irrigation, and nongrowing

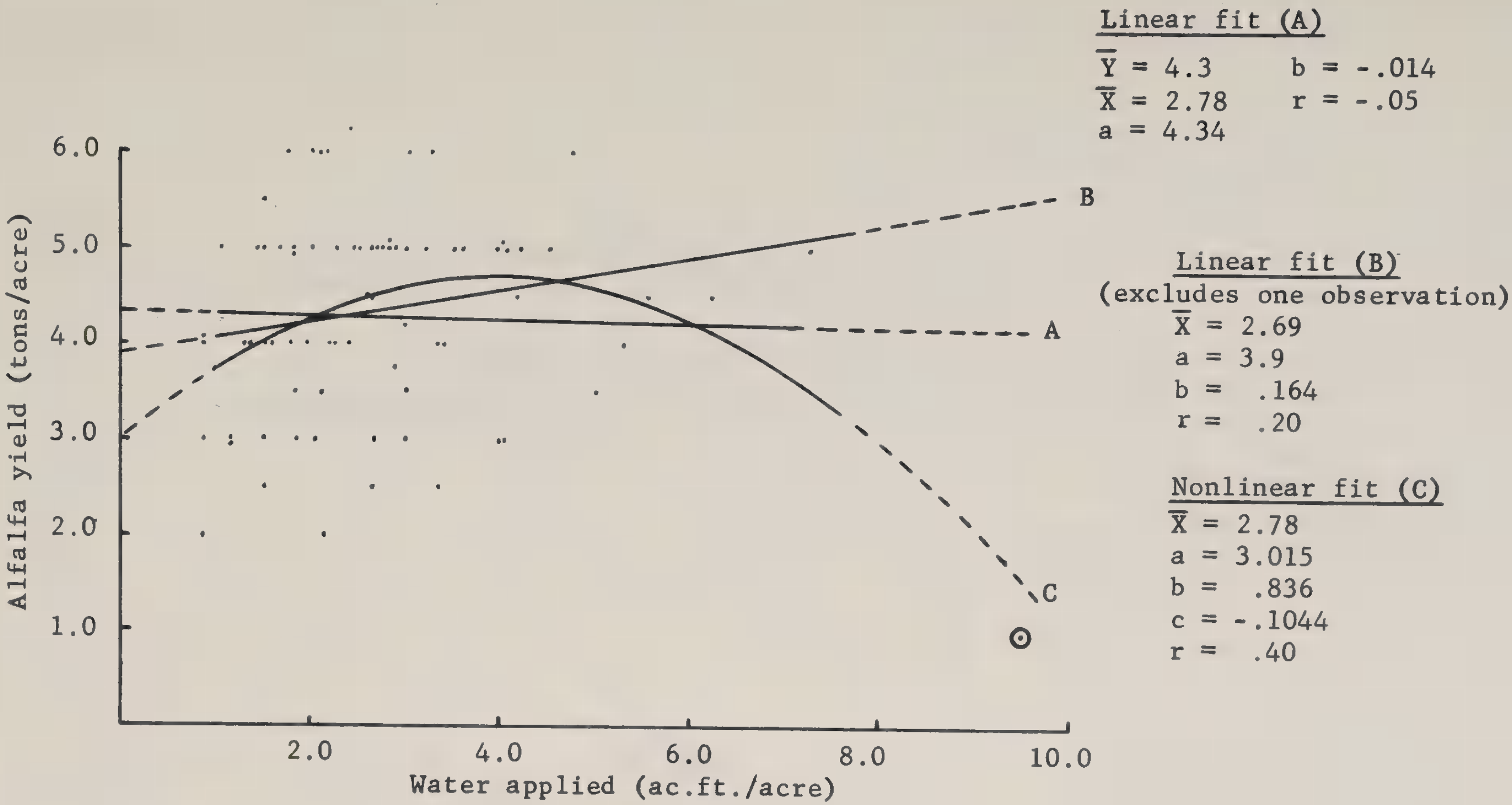


Figure 3. Alfalfa yield and irrigation water applied on sample fields, Sevier Valley, 1962.

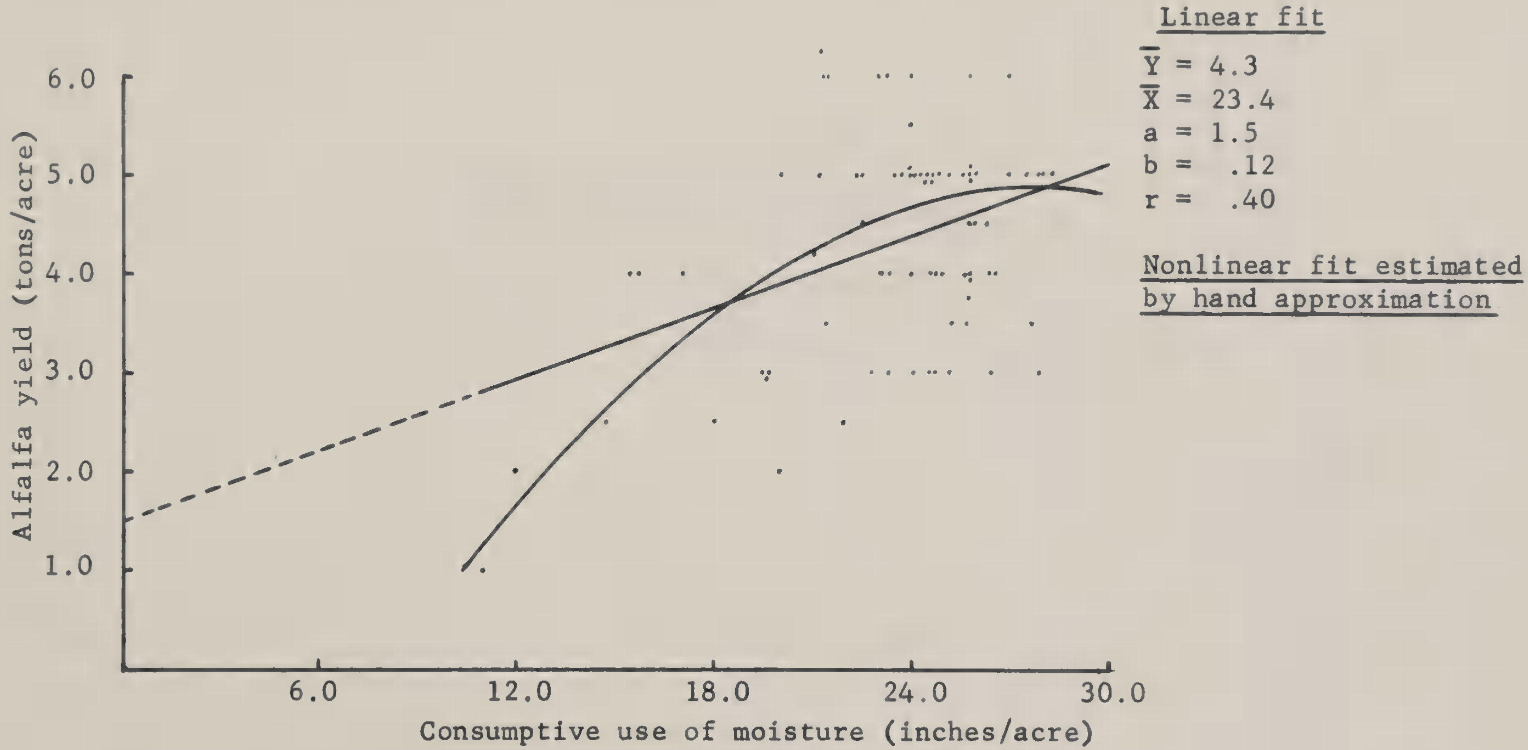


Figure 4. Alfalfa yield and consumptive use of moisture during the growing season on sample fields, Sevier Valley, 1962

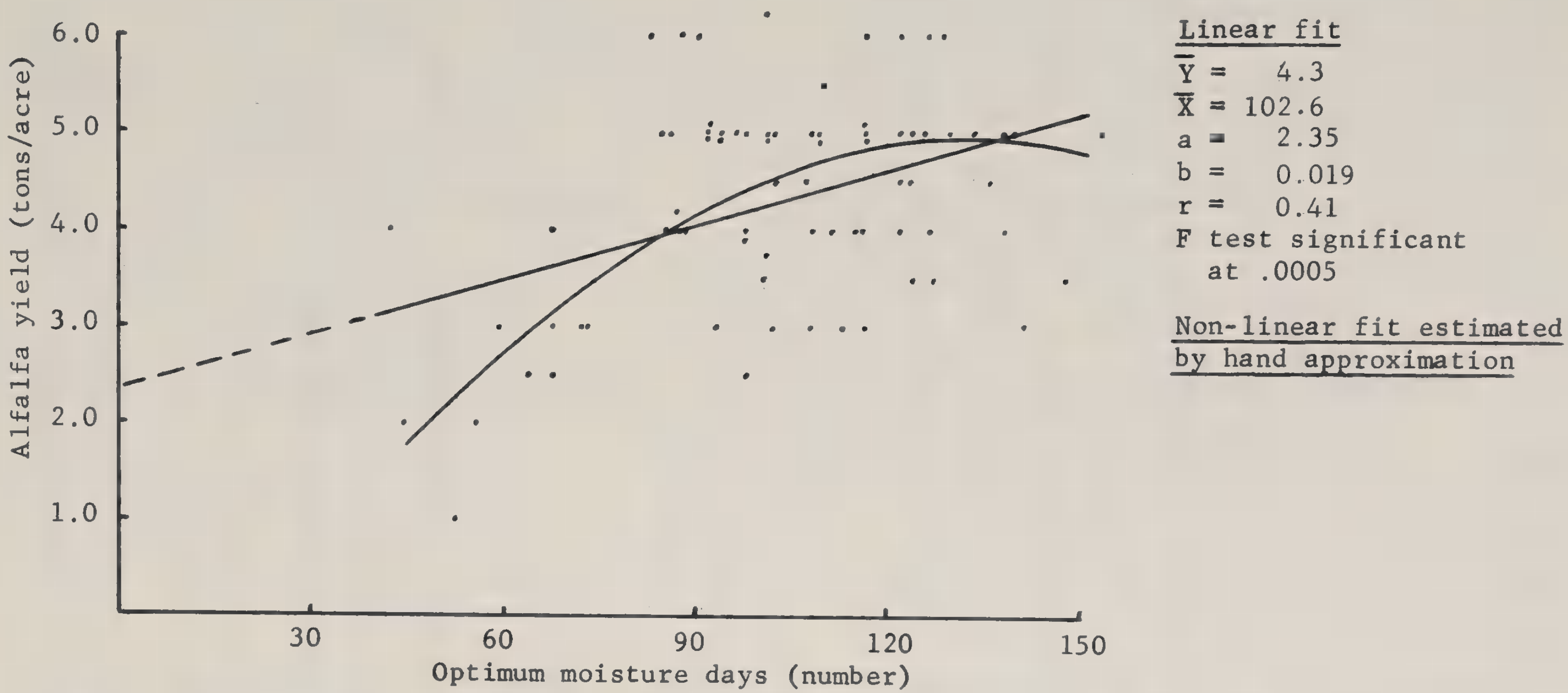


Figure 5. Alfalfa yields and optimum moisture days in the growing season on sample fields, Sevier Valley, 1962.

season water had an increasing effect at the lower levels and decreasing effects at the higher levels.

Model Building Program

The model-building program shows numerically the effects of alfalfa yield of different levels of resource use and combinations of resource uses. The procedure divides the observations for each variable and combination of variables into high, middle, and low groups and gives the mean yields for all combinations of groups. Figure 6 shows graphically the results of the program for selected combinations of variables. Results indicate that there were strong interaction effects between water use and soil surface texture, subsoil permeability, fertilizer use, years in rotation, total growing days, and the date of first irrigation. In addition, interaction terms between water management variables were identified for use in the study.

Correlation Analysis

Simple correlation coefficients for all combinations of linear independent variables and the dependent variables are shown in Table 17. The highest correlation for the independent variables to alfalfa yield were obtained for optimum moisture days and consumptive use of moisture during the growing season. The correlations between alfalfa yield and irrigation water applied in the growing season and during the nongrowing season were negative and low in both cases.

The correlation was relatively high in some cases between independent linear variables. High positive correlations were obtained between soil surface texture and soil permeability, consumptive use of moisture

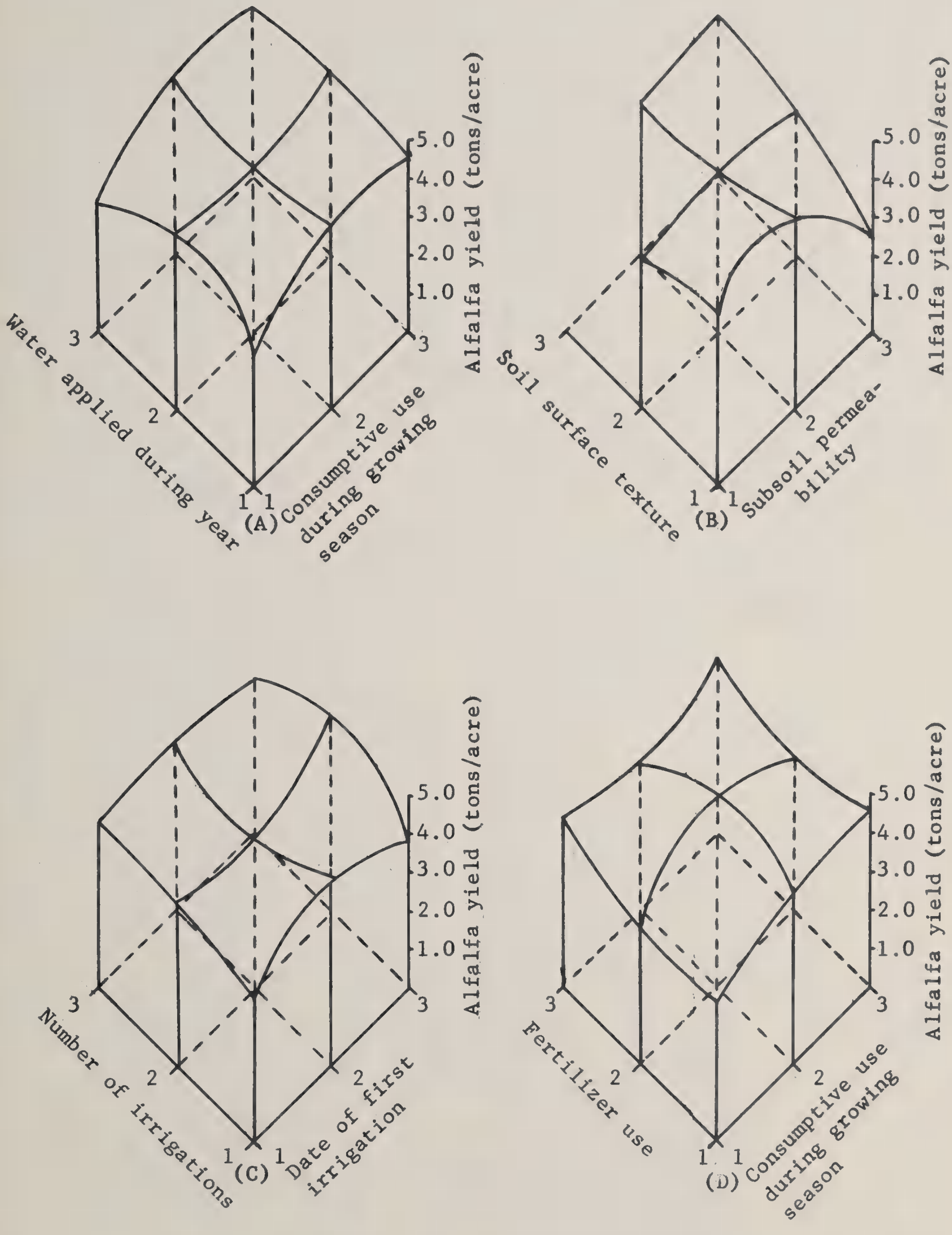


Figure 6. Main and two-way interaction effects of combinations of variables on alfalfa yields, Sevier Valley, 1962.

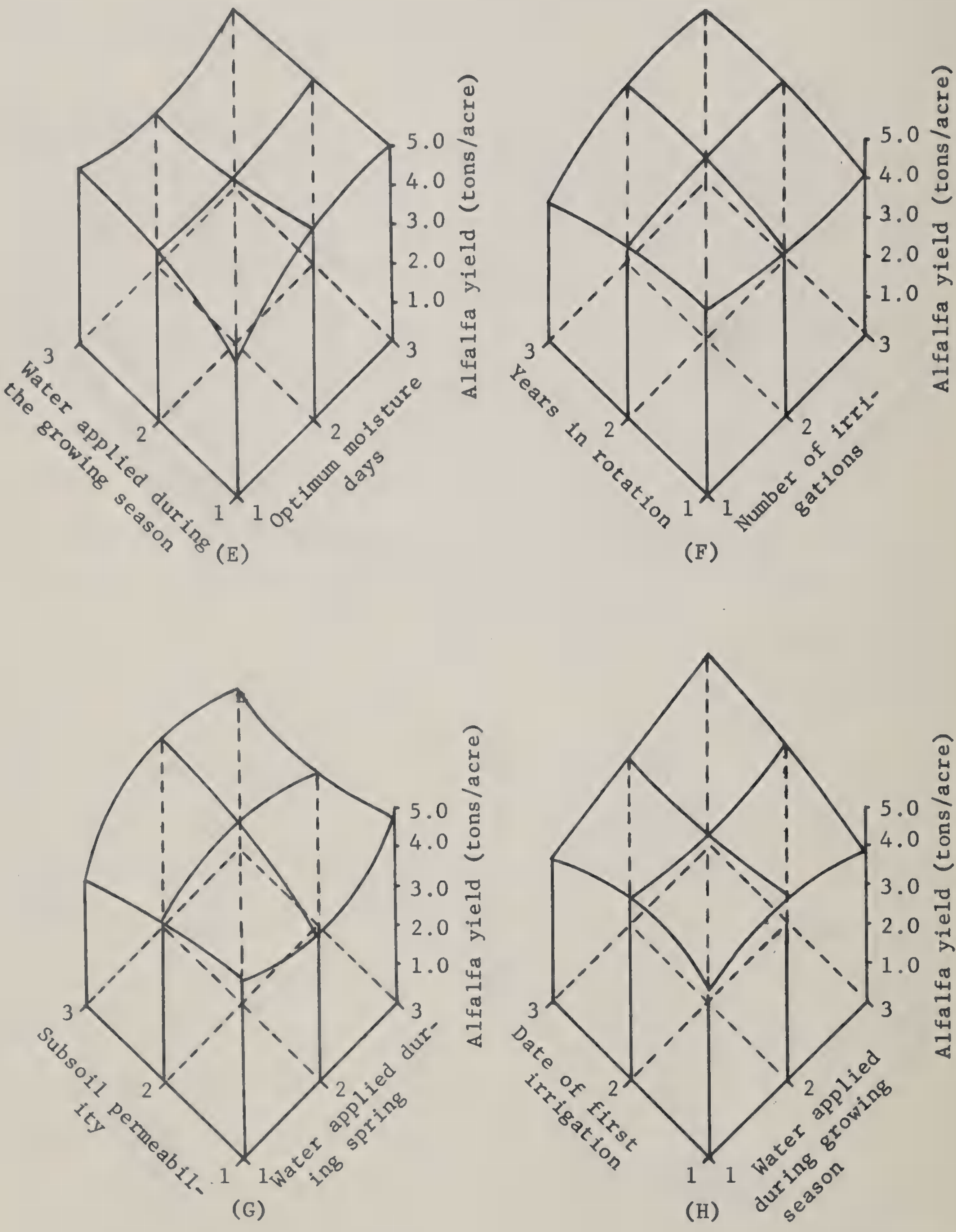


Figure 6.- continued

Table 17. Simple correlation coefficients for linear factors associated with alfalfa yield, Sevier Valley, 1962

Identification Code	Variable	Total yield	Soil surface texture	Soil permeability	Slope	Fertilizer use	Total growing days	Years in rotation	Number of irrigations	Date of: first irrigation	Nongrowing season water	Water in growing season	Optimum moisture days	Consumptive use in growing season
Y	Total yield	-----												
T	Soil surface texture	-.067	-----											
P	Soil permeability	-.063	.671	-----										
S	Slope	-.140	.465	.322	-----									
F	Fertilizer use	.089	-.021	-.002	-.078	-----								
G	Total growing days	.273	-.023	-.108	-.101	-.162	-----							
A	Years in rotation	-.303	.170	.171	.164	-.047	-.325	-----						
I	Number of irrigations	.126	-.054	-.038	-.035	.072	.115	-.060	-----					
D	Date of first irrigation	.022	-.181	-.109	-.128	.050	.141	-.036	-.376	-----				
N	Nongrowing season water	-.247	.181	.111	.210	-.083	-.258	.410	.304	-.587	-----			
W	Water in growing season	-.054	-.086	-.076	-.024	-.059	.007	.370	.535	-.163	.508	-----		
O	Optimum moisture days	.412	-.374	-.241	-.336	-.018	.469	-.263	.660	-.084	-.076	.314	-----	
C	Consumptive use in growing season	.395	-.279	-.284	-.256	-.112	.637	-.320	.344	.205	-.368	.103	.777	-----

and total growing days, number of irrigations and optimum moisture days, and optimum moisture days and consumptive use of moisture. A high negative correlation was obtained between nongrowing season water applied and the date of the first irrigation.

Stepwise Multiple Regression Analysis

The stepwise multiple regression program was used to determine the relative contribution of each variable toward explaining the total variation in alfalfa yield. The contribution of each variable can be determined by the change in the coefficient of multiple determination with the elimination of that variable. Consideration has to be given to the linear, nonlinear, and interaction terms for each variable in the model. For example, a linear term for a variable cannot be eliminated and retain the associated nonlinear and interactions terms for further analysis. However, a nonlinear or interaction term for a variable can be eliminated without eliminating the linear term.

Results of the program are shown in Table 18. On this basis its contribution to the total model the days between the first and last irrigation was eliminated from further study. Subsoil permeability was retained as a variable because of the contribution made by the nonlinear and interaction terms.

Multiple Regression Analysis

Twelve variables were included in the multiple regression program. The variables were grouped into three categories for evaluation purposes. The groups included 3 physical variables, 3 nonwater management variables, and 6 water management variables. Linear and nonlinear terms were

Table 18. Order of elimination of variables and coefficients of multiple determination for stepwise multiple regression program

Variable eliminated	Number of variables in model	Value of coefficient of multiple determination
Subsoil permeability	38	0.7130
Soil surface texture x nonseason irrigation water[a]	37	0.7130
Days between first and last irrigation (squared)[a]	36	0.7130
Water in the growing season	35	0.7126
Consumptive use (squared)	34	0.7122
Nonseason water applied x optimum moisture days[a]	33	0.7114
Consumptive use	32	0.7110
Slope x years alfalfa in rotation[a]	31	0.7101
Years alfalfa in rotation	30	0.7082
Soil surface texture x years alfalfa in rotation[a]	29	0.7065
Date of first irrigation (squared)	28	0.7046
Days between first and last irrigation x optimum moisture days[a]	27	0.7024
Days between first and last irrigation[a]	26	0.6975
Soil surface texture (squared)	25	0.6957
Soil surface texture	24	0.6858
Fertilizer use	23	0.6806
Subsoil permeability x nonseason irrigation water	22	0.6730

Table 18. (continued)

Variable eliminated	Number of variables in model	Value of coefficient of multiple determination
Optimum moisture days	21	0.6602
Number of irrigations	20	0.6473
Slope	19	0.6374
Slope (squared)	18	0.6236
Date of first irrigation	17	0.6215
Nonseason irrigation water	16	0.6042
Nonseason irrigation water (squared)	15	0.5928
Subsoil permeability (squared)	14	0.5763
Fertilizer use x consumptive use	13	0.5625
Fertilizer use (squared)	12	0.5455
Total growing days	11	0.5397
Total growing days (squared)	10	0.5211
Soil surface texture x optimum moisture days	9	0.5186
Water in growing season (squared)	8	0.4881
Optimum moisture days (squared)	7	0.4303
Number of irrigations (squared)	6	0.3523
Water in growing season x optimum moisture days	5	0.2931
Number of irrigations x date of first irrigation	4	0.2848
Date of first irrigation x water in growing season	3	0.2716
Years alfalfa in rotation x optimum moisture days	2	0.2640
Years alfalfa in rotation (squared)	1	0.1251

[a]These variables were eliminated from further study.

included for each variable. In addition, 7 linear interaction terms were included in the program. The program was designed to evaluate the contribution each group of variables made toward explaining the variation in alfalfa yield due to different combinations of variables.

The program uses the coefficient of multiple determination (R^2) to measure the percentage of the variation in alfalfa yield that is explained by the variables included in each model. The difference between the value for the coefficient of multiple determination and 1.00 is the unexplained variation in alfalfa yield. The coefficients for each model are not additive to arrive at a total for a group of variables. For example, the sum of the coefficients of multiple determination for the three categories of linear terms (models 1, 3, and 5) is .40. The coefficient for all linear terms considered together is .29 (model 16). This indicates that a portion of the information available in one model considered separately is also available in another model. This situation exists in all models.

By considering all the linear terms (model 16) in the analysis, 29 percent of variation in alfalfa yield is explained. By including the nonlinear terms (model 17) for each variable, the explained variation is increased to 48 percent. With the addition of the 7 interaction terms (model 18) the amount of explained variation was increased by 22 percent to 70 percent.

When the three different categories of variables are considered separately, the water management variables make the most significant contribution. The coefficient of determination for the linear and their squared terms is .37 for the water management group (model 6), .21 for

Table 19. Coefficients of multiple determination obtained with different combinations of factors associated with alfalfa yield

Model number	Independent variables[a]	R2	F ratio	Level of significance[b]
	Group I (physical)			
1	T, P, S	0.020	0.49	NS
2	T, P, S, T^2, P^2, S^2	0.044	0.53	NS
	Group II (nonwater management)			
3	F, G, A,	0.138	3.86	0.025
4	F, G, A, F^2, G^2, A^2	0.206	2.99	0.025
	Group III (water management)			
5	I, D, N, W, O, C	0.242	3.67	0.005
6	I, D, N, W, O, C, I^2, D^2, N^2, W^2, O^2, C^2	0.365	3.02	0.005
7	I, D, N, W, O, C, I^2, D^2, N^2, W^2, O^2, C^2, IxD, DxW, WxO	0.478	3.66	0.0005
	Group IV (physical and nonwater management)			
8	T, P, S, F, G, A	0.144	1.94	0.10
9	T, P, S, T^2, P^2, S^2, F, G, A, F^2, G^2, A^2	0.269	1.93	0.05
	Group V (physical and water management)			
10	T, P, S, I, D, N, W, O, C	0.265	2.64	0.025
11	T, P, S, T^2, P^2, S^2, I, D, N, W, O, C, I^2, D^2, N^2, W^2, O^2, C^2	0.434	2.43	0.01
12	T, P, S, T^2, P^2, S^2, I, D, N, W, O, C, I^2, D^2, N^2, W^2, O^2, C^2, IxD, DxW, WxO	0.534	2.95	0.005
19	T, P, S, I, D, N, W, O, C, TxO, PxN, IxD, DxW, WxO	0.467	3.82	0.0005

Table 19. (continued)

Model number	Independent variables[a]	R2	F ratio	Level of significance[b]
	Group VI (nonwater and water management)			
13	F, G, A, I, D, N, W, O, C	0.263	2.62	0.025
14	F, G, A, F^2, G^2, A^2, I, D, N, W, O, C, I^2, D^2, N^2, W^2, O^2, C^2	0.401	2.12	0.025
15	F, G, A, F^2, G^2, A^2, I, D, N, W, O, C, I^2, D^2, N^2, W^2, O^2, C^2, IxD, DxW, WxO	0.543	3.05	0.001
20	F, G, A, I, D, N, W, O, C, FxC, AxO, IxD, DxW, WxO	0.421	3.17	0.001
	Group VII (physical, nonwater and water)			
16	T, P, S, F, G, A, I, D, N, W, O, C	0.292	2.16	0.025
17	T, P, S, T^2, P^2, S^2, F, G, A, F^2, G^2, A^2, I, D, N, W, O, C, I^2, D^2, N^2, W^2, O^2, C^2	0.477	1.94	0.025
18	T, P, S, T^2, P^2, S^2, F, G, A, F^2, G^2, A^2, I, D, N, W, O, C, I^2, D^2, N^2, W^2, O^2, C^2, TxO, PxN, FxC, AxO, IxD, DxW, WxO	0.698	3.28	0.0005
21	T, P, S, F, G, A, I, D, N, W, O, C, TxO, PxN, FxC, AxO, IxD, DxW, WxO	0.500	2.95	0.001
	Group VIII (special combinations)			
22	T, S, F, A, N, W, T^2, S^2, F^2, A^2, N^2, W^2	0.239	1.65	NS
23	T, S, A, I, T^2, S^2, F^2, A^2, I^2	0.223	2.10	0.05
24	T, S, F, G, A, D, O, TxO, T^2, S^2, F^2, G^2, A^2, D^2, O^2	0.399	2.65	0.005
25	T, S, F, A, C, FxC, T^2, S^2, F^2, A^2, C^2	0.347	3.09	0.005

Table 19. (continued)

Model number	Independent variables[a]	R2	F ratio	Level of significance[b]
26	T, S, F, G, A, D, C, FxC, T^2, S^2, F^2, G^2, A^2, D^2, C^2	0.412	2.80	0.005
27	G, I, D, O, G^2, I^2, D^2, O^2	0.292	3.46	0.005
28	A, O, AxO, A^2, O^2	0.339	7.17	0.0005
29	A, I, D, N, W, IxD, A^2, I^2, D^2, N^2, W^2	0.203	1.48	NS
30	T, F, A, I, D, W, O, C, TxO, FxC, AxO, IxD, DxW, WxO, T2, F2, A2, I^2, D^2, W^2, O^2, C^2	0.550	2.96	0.001

[a]See Table 17 for variable identification code.

[b]Values indicate the probability of getting the indicated F value under the hypothesis that the slope of the regression line is zero.

the nonwater management group (model 4), and .04 for the physical group (model 2). When combinations of the groups are considered, it becomes evident that there is considerable duplication of information between the water management and the nonwater management groups. The coefficient for the combined groups (model 14) is .40. This is only a 3-percent gain in information over the water management group considered separately. The situation is considerably different when the physical group is combined with the other groups. The coefficient for the physical and nonwater management group (model 9) is .27. This is a 2-percent gain over the sum of the information when you consider the groups alone. The same situation occurs in model 11 where the physical and water management variables are evaluated together.

Models 22 to 30 were designed to evaluate the different water management variables in combination with other groups as predicted models for use in water resource evaluation. A considerable loss of information is evident when the number of water management variables is reduced. Evaluation of the different models indicate that optimum moisture days (model 24) and consumptive use of moisture (model 26) are better measures of irrigation water use than the number of irrigations (model 23) or gross amounts of irrigation applied (model 22). Model 24 and 26 are about equal in the amount of information contained in the models. Evaluation of model 28 indicates that a large portion of the information in other models can be gained by using the years in rotation with a corresponding water variable.

Evaluation of Models

Models 18, 24, 26, and 28 were selected for testing as predictive models for use in the evaluation of increments of irrigation water. In general, it is recognized that intercorrelation problems exist in all models, but this problem is compounded as the number of variables are increased in the models. When a multiple regression model is employed, a correlation structure influences regression values. Individual variables, therefore, can not be varied over a range of situations, while the remaining variables are held constant, without being influenced by the correlation structure. This point is illustrated when the regression values for consumptive use of moisture are compared between models 18 and 26. In model 18 the linear term for consumptive use is negative and the squared term is negative. Examination of the functional relationship of consumptive use to alfalfa yield established earlier in the study shows that the relationship in model 26 is consistent with the relationship expected. This situation can be explained by the correlation structure that was developed by the inclusion of several water management variables in model 18.

In general terms, the inclusion of a large number of variables in a model increases the coefficient of multiple correlation. Models which have a smaller number of variables also have a smaller coefficient and fewer intercorrelation problems.

Model 18

Model 18 contains 12 linear terms, 12 nonlinear terms, and 7 interaction terms. A coefficient of determination of .70 was obtained. The

F test indicates that the model is significant at the .0005 probability level.

The mean values and associated regression values for each variable are shown in Tables 20 and 21. The corresponding analysis of variance for each variable is shown in Table 22. The size of the F ratio for each variable is an indication of the amount of contribution that each variable makes to the over-all model.

Evaluation of the model indicates that intercorrelation problems between variables make this model useless for predicting changes in alfalfa yields due to changes in individual variables.

The regression values for slope, total growing days, years alfalfa in rotation, date of first irrigation, and nonseason irrigation water correspond with expected functional relationships. The values for other linear and squared terms are different than would be expected. The intercorrelation problems in the model seem to be centered around the water management variables.

Model 24

Model 24 contains 7 linear terms, 7 nonlinear terms, and 1 interaction term. A coefficient of determination of .40 was obtained. The F test indicates that the model is significant at the .005 probability level.

The regression values and corresponding analysis of variance for factors in the model are shown in Tables 23 and 24. All regression values except squared term for fertilizer use correspond with expected functional relationships. The F ratios in Table 24 indicate that slope and optimum moisture days are the most significant variables in the model. Soil

Table 20. Variable identification and mean values for different factors associated with alfalfa hay production

Code	Variable	Mean value
Y	Total alfalfa yield	4.299
T	Soil surface texture	2.447
P	Subsoil permeability	2.539
S	Slope	1.553
F	Fertilizer use	25.263
G	Total growing days	132.816
A	Years in rotation	6.118
I	Number of irrigations	4.553
D	Date of first irrigation	117.711
N	Nongrowing season water	0.436
W	Water in growing season	2.386
O	Optimum yield days	102.592
C	Consumptive use in growing season	23.418
TxO	Soil texture x optimum yield days	245.987
PxN	Subsoil permeability x nongrowing season water	1.149
FxC	Fertilizer use x consumptive use in growing season	577.183
AxO	Years in rotation x optimum yield days	612.461
IxD	Number of irrigations x date of first irrigation	524.145
DxW	Date of first irrigation x water in growing season	276.525
WxO	Water in growing season x optimum yield days	255.155

Table 20. (continued)

Code	Variable	Mean value
T^2	Soil surface texture (squared)	6.316
P^2	Subsoil permeability (squared)	6.776
S^2	Slope (squared)	3.316
F^2	Fertilizer use (squared)	1957.316
G^2	Total growing days (squared)	17,853.263
A^2	Years in rotation (squared)	43.355
I^2	Number of irrigations (squared)	23.368
D^2	Date of first irrigation (squared)	14,224.105
W^2	Water in growing season (squared)	7.605
N^2	Nongrowing season water (squared)	0.638
O^2	Optimum yield days (squared)	11,094.171
C^2	Consumptive use in growing season (squared)	561.030

Table 21. Regression values for different factors associated with alfalfa production, model 18

Code	Variable	Regression coefficient
bo		-18.36550
T	Soil surface texture	-4.15378
P	Subsoil permeability	-0.12389
S	Slope	+0.48938
F	Fertilizer use	+0.03719
G	Total growing days	+0.42808
A	Years in rotation	+0.03441
I	Number of irrigations	+0.81799
D	Date of first irrigation	+0.06414
N	Nongrowing season water	+2.51408
W	Water in growing season	+0.37844
O	Optimum yield days	-0.15152
C	Consumptive use in growing season	-0.02260
TxO	Soil texture x optimum yield days	+0.02831
PxN	Subsoil permeability x nongrowing season water	-0.50849
FxC	Fertilizer use x consumptive use in growing season	-0.00242
AxO	Years in rotation x optimum yield days	-0.00567
IxD	Number of irrigations x date of first irrigation	-0.01367
DxW	Date of first irrigation x water in growing season	+0.01329

Table 21. (continued)

Code	Variable	Regression coefficient
WxD	Water in growing season x optimum yield days	-0.03136
T^2	Soil surface texture (squared)	+0.43754
P^2	Subsoil permeability (squared)	-0.08187
S^2	Slope (squared	-0.10567
F^2	Fertilizer use (squared)	+0.00019
G^2	Total growing days (squared)	-0.00168
A^2	Years in rotation (squared)	-0.05035
I^2	Number of irrigations (squared)	+0.04787
D^2	Date of first irrigation (squared)	-0.00011
W^2	Water in growing season (squared)	+0.29430
N^2	Nongrowing season water (squared)	-0.71216
O^2	Optimum yield days (squared)	+0.00077
C^2	Consumptive use in growing season (squared)	+0.00053

Table 22. Analysis of variance, model 18

Code	Source	df	M.S.	F ratio	Level of significance
T	Soil surface texture	1	1.07456	1.73	NS
P	Subsoil permeability	1	0.00267	0.00	NS
S	Slope	1	1.04048	1.67	NS
F	Fertilizer use	1	1.48017	2.38	NS
G	Total growing days	1	6.05682	9.73	0.005
A	Years in rotation	1	0.00282	0.00	NS
I	Number of irrigations	1	0.59407	0.95	NS
D	Date of first irrigation	1	0.64806	1.04	NS
N	Nongrowing season water	1	2.76062	4.43	0.05
W	Water in growing season	1	0.05495	0.09	NS
O	Optimum yield days	1	1.78639	2.87	0.10
C	Consumptive use in growing season	1	0.00179	0.00	NS
TxO	Soil surface texture x optimum yield days	1	2.02919	3.26	0.10
PxN	Subsoil permeability x nongrowing season water	1	0.67103	1.08	NS
FxC	Fertilizer use x consumptive use in growing season	1	3.75836	6.03	0.025
AxO	Years in rotation x optimum yield days	1	2.84219	4.56	0.05
IxD	Number of irrigations x date of first irrigation	1	3.84623	6.18	0.025
DxW	Date of first irrigation x water in growing season	1	2.79971	4.50	0.05

Table 22. (continued)

Code	Source	df	M.S.	F ratio	Level of signifi- cance
WxO	Water in growing season x optimum yield days	1	8.71887	14.00	0.001
T^2	Soil surface texture (squared)	1	0.65730	1.06	NS
P^2	Subsoil permeability (squared)	1	0.03580	0.06	NS
S^2	Slope (squared)	1	1.18105	1.90	NS
F^2	Fertilizer use (squared)	1	1.61889	2.60	NS
G^2	Total growing days (squared)	1	6.25373	10.04	0.005
A^2	Years in rotation (squared)	1	2.04531	3.28	0.10
I^2	Number of irrigations (squared)	1	0.79089	1.27	NS
D^2	Date of first irrigation (squared)	1	0.12092	0.19	NS
W^2	Nongrowing season water (squared)	1	1.97837	3.18	0.10
O^2	Optimum yield days (squared)	1	3.55715	5.71	0.025
C^2	Consumptive use in growing season (squared)	1	0.00201	0.00	NS
	Residual	44	0.62278		

Table 23. Regression values for different factors associated with alfalfa production, model 24

Code	Variable	Regression coefficient
b_0		-9.24848
T	Soil surface texture	-0.02032
S	Slope	+0.67329
F	Fertilizer use	+0.00067
G	Total growing days	+0.10475
A	Years in rotation	+0.02001
D	Date of first irrigation	+0.02360
O	Optimum yield days	+0.08328
TxO	Soil surface texture x optimum yield days	+0.00331
T^2	Soil surface texture (squared)	-0.00458
S^2	Slope (squared)	-0.13913
F^2	Fertilizer use (squared)	+0.00003
G^2	Total growing days (squared)	-0.00041
A^2	Years in rotation (squared)	-0.00483
D^2	Date of first irrigation (squared)	-0.00011
O^2	Optimum yield days (squared)	-0.00038

Table 24. Analysis of variance, model 24

Code	Source	df	M.S.	F ratio	Level of significance
T	Soil surface texture	1	0.00005	0.00	NS
S	Slope	1	2.69748	2.97	0.10
F	Fertilizer use	1	0.00451	0.00	NS
G	Total growing days	1	0.72303	0.80	NS
A	Years in rotation	1	0.01233	0.01	NS
D	Date of first irrigation	1	0.15328	0.17	NA
O	Optimum yield days	1	1.07335	1.18	NS
TxO	Soil surface texture x optimum yield days	1	0.04537	0.05	NS
T^2	Soil surface texture (squared)	1	0.00013	0.00	NS
S^2	Slope (squared)	1	2.83948	3.13	0.10
F^2	Fertilizer use (squared)	1	0.08489	0.09	NS
G^2	Total growing days (squared)	1	0.71873	0.79	NS
A^2	Years in rotation (squared)	1	0.24167	0.27	NS
D^2	Date of first irrigation (squared)	1	0.14760	0.16	NS
O^2	Optimum yield days (squared)	1	2.45858	2.71	0.25
	Residual	60	0.90843		

surface texture, fertilizer use, years in rotation, and date of first irrigation have a lesser influence on the model.

The predicted values for optimum moisture days in combination with soil surface texture, fertilizer use, years in rotation, and slope are shown in Figure 7. Alfalfa yield is at a maximum with 120 optimum moisture days, 2.1 years in rotation, 2.4 percent slope, 128 growing days, and 1 nongrowing season irrigation. No maximum yield is indicated within the ranges of fertilizer use and soil surface texture considered.

The model indicates that fertilizer use is increasing at an increasing rate over the range of situations in the model and therefore no maximum yield level can be shown. The predicted values for soil surface texture seem to indicate an intercorrelation problem between slope and soil surface texture. The predicted values indicate that alfalfa yield is at a maximum in a moderately heavy soil surface texture.

Model 26

Model 26 contains 7 linear terms, 7 nonlinear terms, and 1 interaction term. A coefficient of determination of .41 was obtained for this model. The F test indicates that the model is significant at the .005 level.

The regression values and corresponding analysis of variance for each factor in the model are shown in Tables 25 and 26. All regression values except the linear and squared terms for years alfalfa in rotation, the squared term for soil surface texture, and the squared term for fertilizer use correspond with the expected functional relationships. The F ratios indicate that slope, total growing days, and consumptive use of

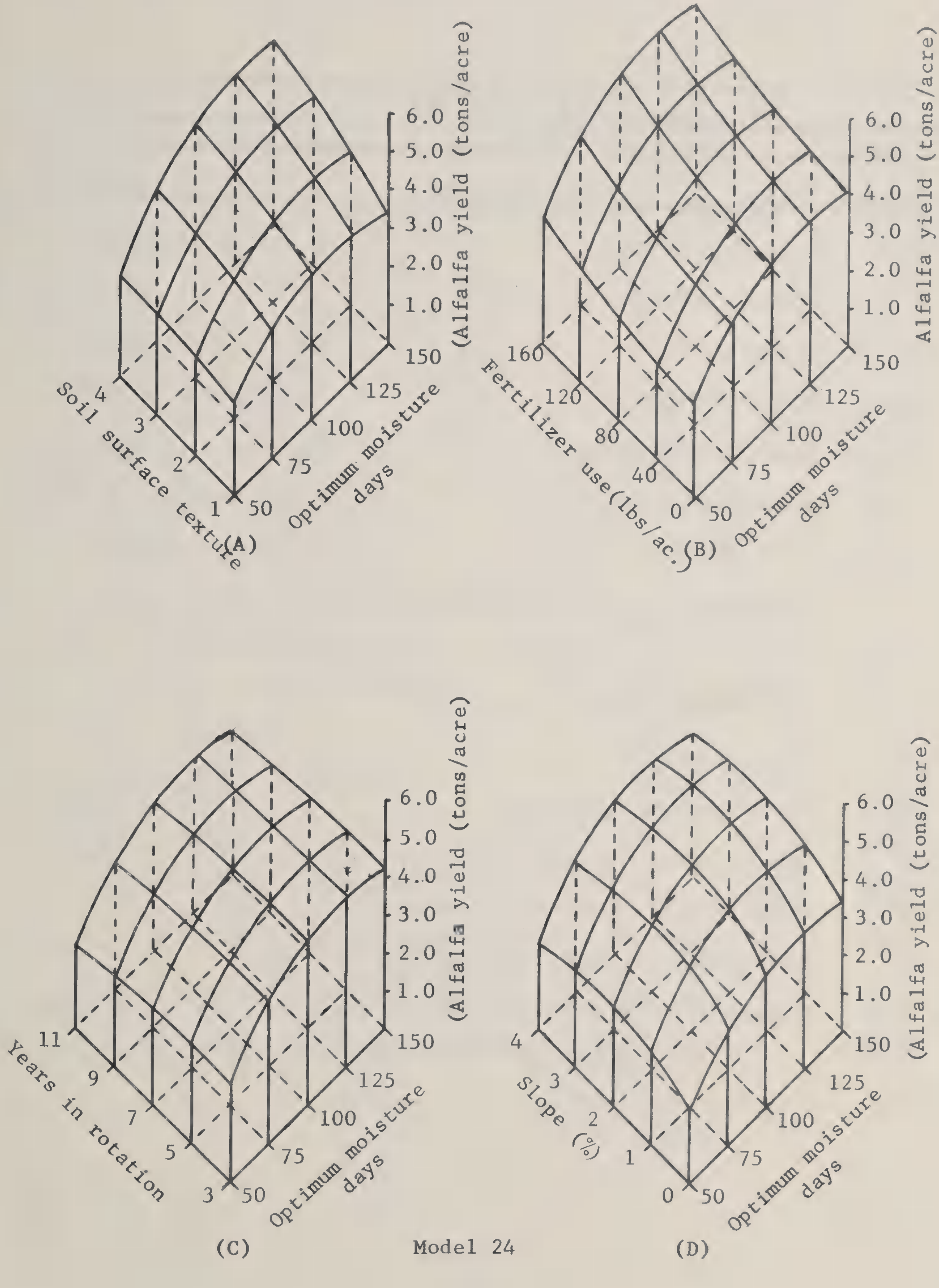


Figure 7. Predicted relationships between optimum moisture days and soil surface texture, fertilizer use, years in rotation and slope, Sevier Valley, 1962.

Table 25. Regression values for different factors associated with alfalfa production, model 26

Code	Variable	Regression coefficient
bo		+24.82340
T	Soil surface texture	-0.02394
S	Slope	+0.91360
F	Fertilizer use	+0.02303
G	Total growing days	+0.25209
A	Years in rotation	-0.19698
D	Date of first irrigation	+0.05256
C	Consumptive use in growing season	+0.79339
FxC	Fertilizer use x consumptive use in growing season	-0.00141
T^2	Soil surface texture (squared)	+0.04164
S^2	Slope (squared)	-0.19119
F^2	Fertilizer use (squared)	+0.00016
G^2	Total growing days (squared)	-0.00097
A^2	Years alfalfa in rotation (squared)	+0.01152
D^2	Date of first irrigation (squared)	-0.00026
C^2	Consumptive use in growing season (squared)	-0.01494

Table 26. Analysis of variance, model 26

Code	Source	df	M.S.	F ratio	Level of signifi-cance
T	Soil surface texture	1	0.00014	0.00	NS
S	Slope	1	4.91553	5.53	0.025
F	Fertilizer use	1	0.92668	1.04	NS
G	Total growing days	1	4.18789	4.71	0.05
A	Years in rotation	1	1.20081	1.35	NS
D	Date of first irrigation	1	0.84496	0.95	NS
C	Consumptive use in growing season	1	4.21862	4.75	0.05
FxC	Fertilizer use x consumptive use in growing season	1	2.29281	2.58	NS
T^2	Soil surface texture (squared)	1	0.01107	0.01	NS
S^2	Slope (squared)	1	5.48315	6.17	0.025
F^2	Fertilizer use (squared)	1	2.65534	2.99	NS
G^2	Total growing days (squared)	1	4.14187	4.66	0.05
A^2	Years in rotation (squared)	1	1.22013	1.37	NS
D^2	Date of first irrigation (squared)	1	1.04873	1.18	NS
C^2	Consumptive use in growing season (squared)	1	2.74910	3.09	NS
	Residual	60	0.88829		

moisture are the most significant variables in the model. In general, the F ratios suggest that all factors except soil surface texture provide some information to the total model.

The predicted values for consumptive use of moisture in combination with soil surface texture, fertilizer use, years alfalfa in rotation, and slope are shown in Figure 8. Alfalfa yield is at a maximum when 25.4 inches of moisture is consumptively used in 129 growing days. Maximum yield level is attained with 2.4 percent slope. No maximum yield is attained within the ranges considered for soil surface texture, fertilizer use, and years alfalfa in rotation. Yield is increasing at an increasing rate with increased fertilizer use.

Model 28

Model 28 contains 2 linear terms, 2 nonlinear terms, and 1 interaction term. A coefficient of determination of .34 was obtained. The F test indicates that the model is significant at the .0005 probability level.

The regression values and the corresponding analysis of variance for factors in the model are shown in tables 27 and 28. All the regression values except the squared term for years in rotation correspond with expected functional relationships. The F ratios in Table 28 indicate that optimum moisture days and the interaction term between optimum moisture days and years in rotation are the most significant variables in the model.

The predicted values for optimum moisture days and years alfalfa in rotation are shown in Figure 9. Alfalfa yield is at a maximum at 124 optimum moisture days. No maximum yield is attained for years

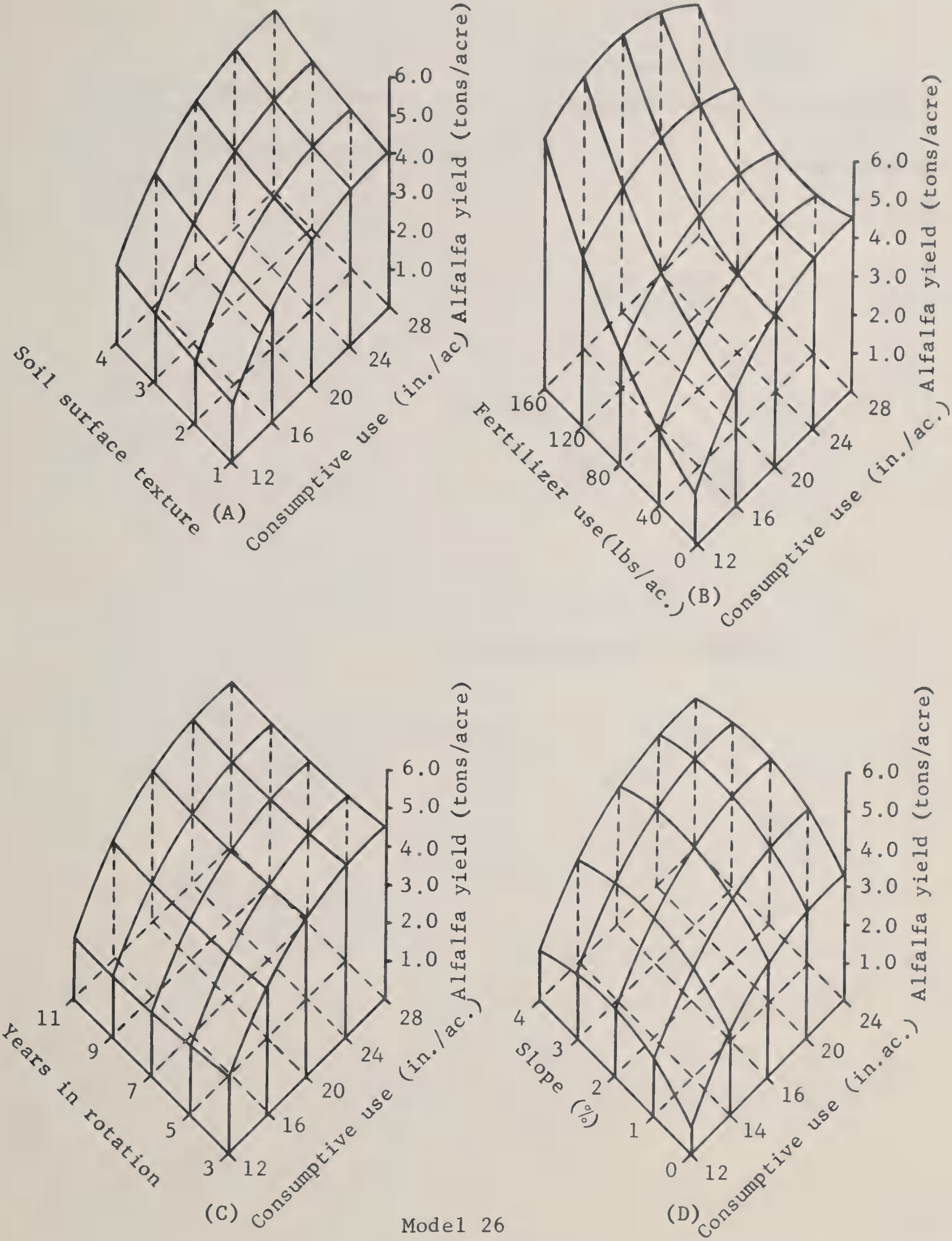


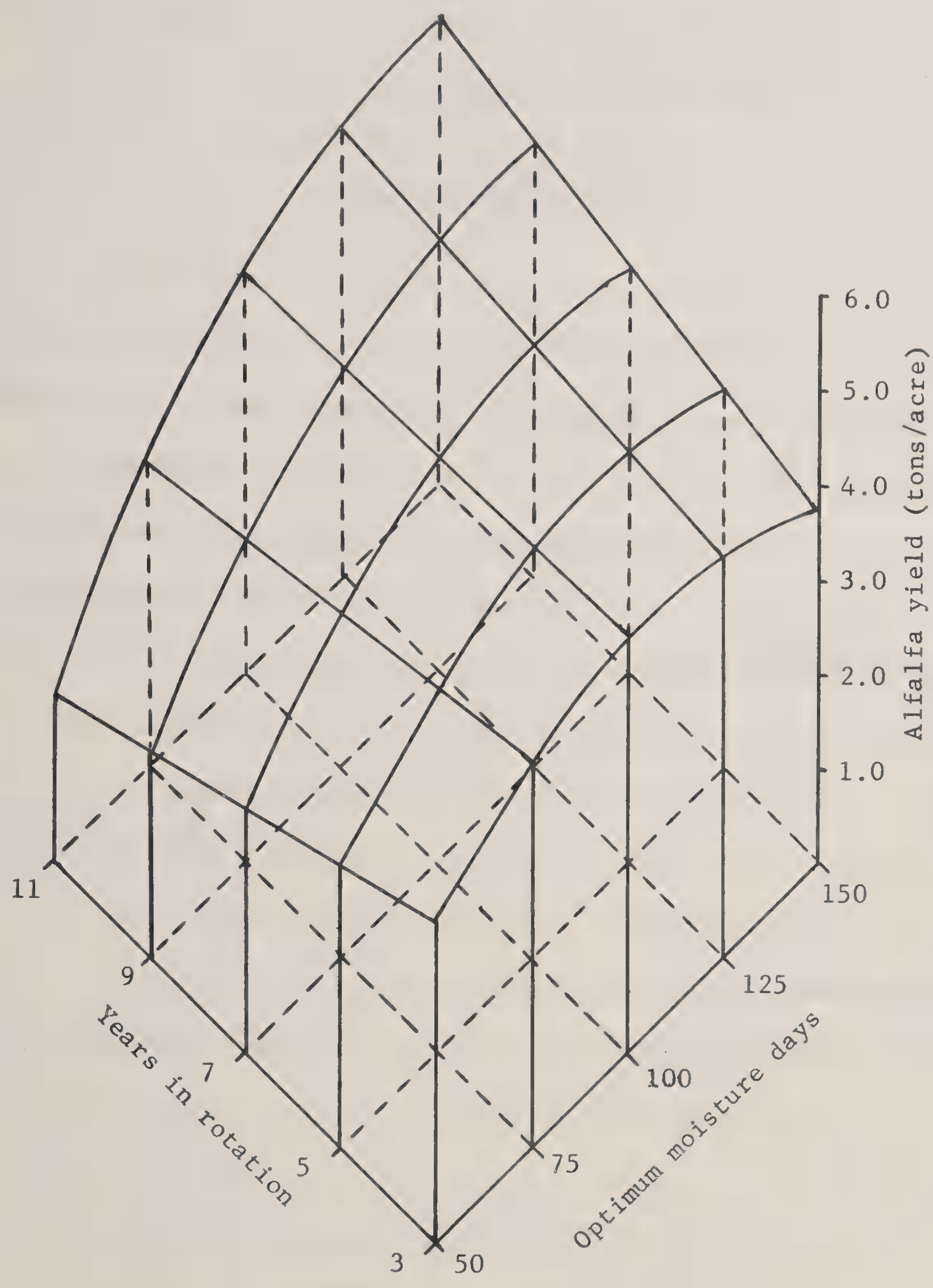
Figure 8. Predicted relationship between consumptive use of moisture in the growing season and soil surface texture, fertilizer use, years in rotation and slope, Sevier Valley, 1962.

Table 27. Regression values for different factors associated with alfalfa production, model 28

Code	Variable	Regression coefficient
bo		+2.24760
A	Years in rotation	-0.40666
O	Optimum yield days	+0.05761
AxO	Years in rotation x optimum yield days	+0.00346
A^2	Years in rotation (squared)	+0.00226
O^2	Optimum yield days (squared)	-0.00032

Table 28. Analysis of variance, model 28

Code	Source	df	M.S.	F ratio	Level of significance
A	Years in rotation	1	0.73754	0.86	NS
O	Optimum yield days	1	1.68406	1.97	0.25
AxO	Years rotation x optimum yield days	1	1.52089	1.78	0.25
A^2	Years in rotation (squared)	1	0.02786	0.03	NS
O^2	Optimum yield days (squared)	1	3.52255	4.11	0.05
	Residual	70	0.85642		



Model 28

Figure 9. Predicted relationship between optimum moisture days and years alfalfa in rotation, Sevier Valley, 1962.

alfalfa in the rotation. The predicted values for alfalfa yield at the higher number of optimum moisture days and years in rotation show yield increasing; this is contrary to the expected values. This situation is probably caused by the linear interaction term in the model.

Economic Implications

The purpose of this section is to illustrate the application of economics to the results of this study. It is recognized that the information provided by the multiple regression models in this study have problems associated with the correlation structure developed in the models. The correlation problems are more apparent in some models and variables than others. For example, the results for consumptive use of moisture in the growing season in model 26 conformed to the expected relationship, while the predicted relationship for fertilizer use in the same model does not fall within the expected ranges.

Once the physical productivity of irrigation water has been established for all alternative uses, the economic productivity in different uses can be determined by attaching monetary values to output and resource inputs. The most economical use of water on one crop can be determined by equating marginal cost (MC) of the water resource to the marginal revenue (MR) produced with its use. For more than one crop the optimal allocation from an economic viewpoint is the point at which the marginal revenue is equal in all alternative uses.

The physical productivity of irrigation water established in model 26 (consumptive use of water in the growing season) with 3 years alfalfa in rotation was used to illustrate the economic productivity

of irrigation water applied to alfalfa. The prices of output and inputs are the average prices reported by farmers in the area. Average custom hire rates, wage rates, labor inputs, taxes, and land values were used to determine production costs shown in Table 29. Interest on investment in land and inventory was charged at 5 percent. Labor inputs were charged at $1.25 per hour. The net return shown is the return to management.

Figure 10 shows the stages of economic production. Stages 1 and 3 represent the areas of uneconomical production. The economical or rational area (stage 2) of production is the area between points A and B. Physical productivity is a maximum with 43.3 inches of irrigation water applied. The most economical point of water use is at 40.0 inches of water applied and 24.0 inches of moisture consumptively used in the growing season. Net income at this point is $11.61 per acre. Figures 11 and 12 illustrate the determination of this point. Point A represents the break-even level of production. Point B is the most economical level of production. Marginal revenue and marginal cost are equal and the distance between total revenue and total cost is also the greater at this point. The shaded area represented by point C shows the economic loss from producing at these levels.

Table 29. Estimated physical productivity of irrigation water applied to an acre of alfalfa, Sevier Valley, 1962[a]

Units of variable water inputs: Actual consump-tive use[a]	Units of variable water inputs: Irrigation water applied[b]	Alfalfa yield (TPP)	Addition to total output	Average physical product (APP)	Marginal physical product per unit (MPP)
Inches	Inches	Tons	Tons	Tons	Tons
12	20.0	1.98		0.099	
			0.32		0.188
13	21.7	2.30		0.106	
			0.36		0.225
14	23.3	2.66		0.114	
			0.34		0.200
15	25.0	3.00		0.120	
			0.31		0.194
16	26.7	3.31		0.124	
			0.28		0.175
17	28.3	3.59		0.127	
			0.25		0.147
18	30.0	3.84		0.128	
			0.21		0.124
19	31.7	4.05		0.128	
			0.17		0.106
20	33.3	4.22		0.127	
			0.15		0.082
21	35.0	4.37		0.125	
			0.11		0.075
22	36.7	4.48		0.122	
			0.09		0.050
23	38.3	4.57		0.119	
			0.05		0.024
24	40.0	4.62		0.116	
			0.03		0.018
25	41.7	4.65		0.112	
			0.01		0.006
26	43.3	4.66		0.108	
			-0.05		-0.029
27	45.0	4.61		0.102	
			-0.07		-0.041
28	46.7	4.54		0.097	

[a]Data on physical productivity of irrigation was taken from model 26 for 3 years alfalfa in rotation.

[b]Assumes a 60-percent water application efficiency.

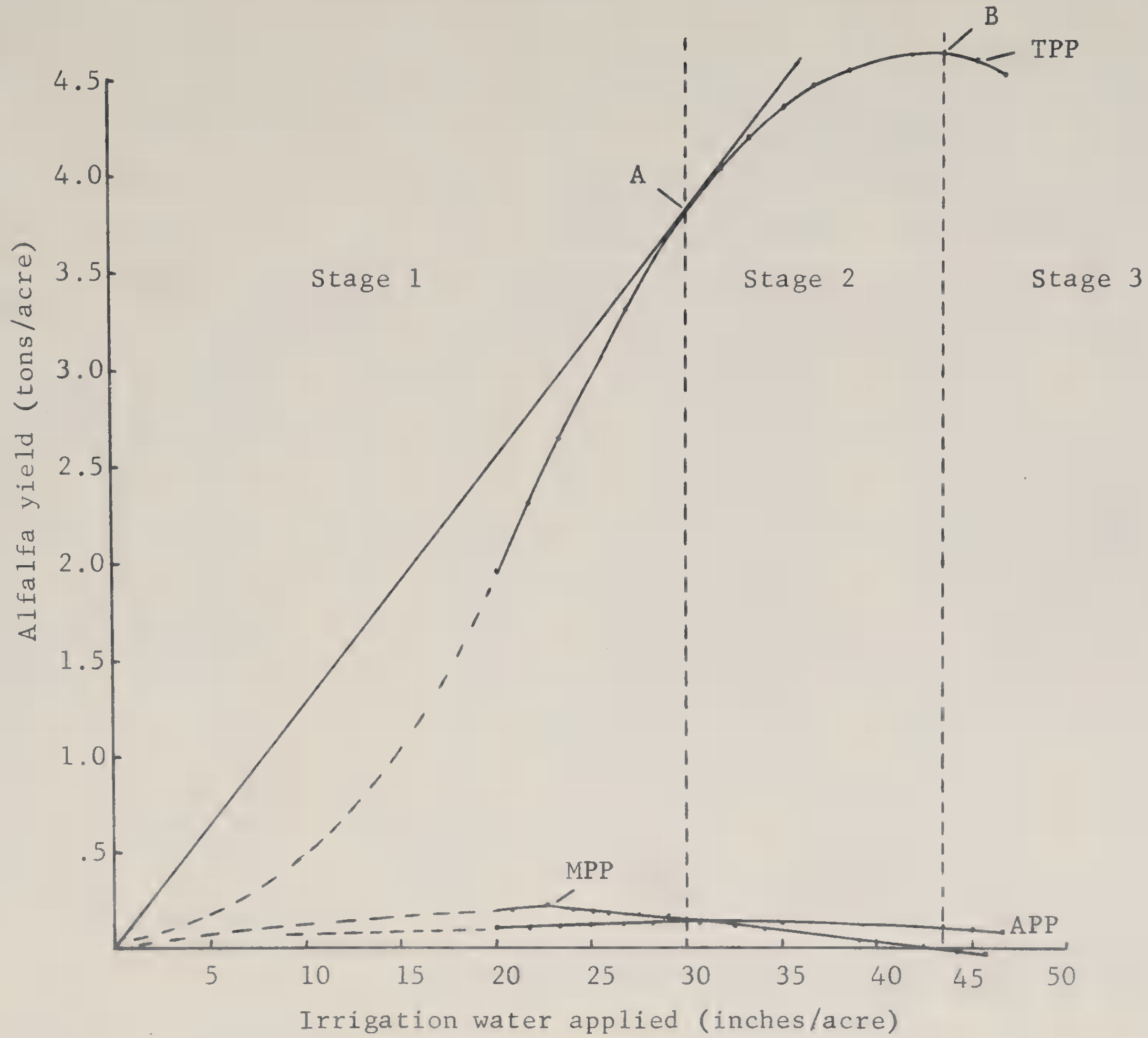


Figure 10. Alfalfa yield and irrigation water-use relationship for Sevier Valley, 1962.

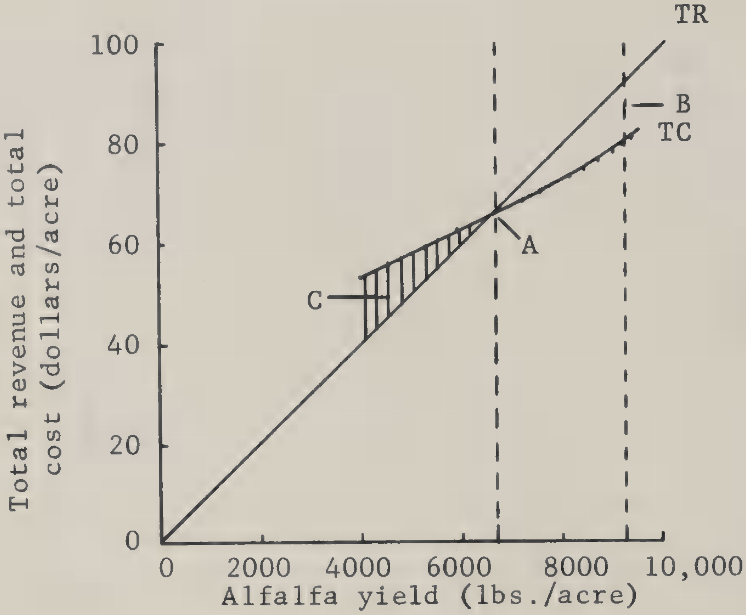


Figure 11. Total revenue and total cost for producing alfalfa at various yield levels, Sevier Valley, 1962.

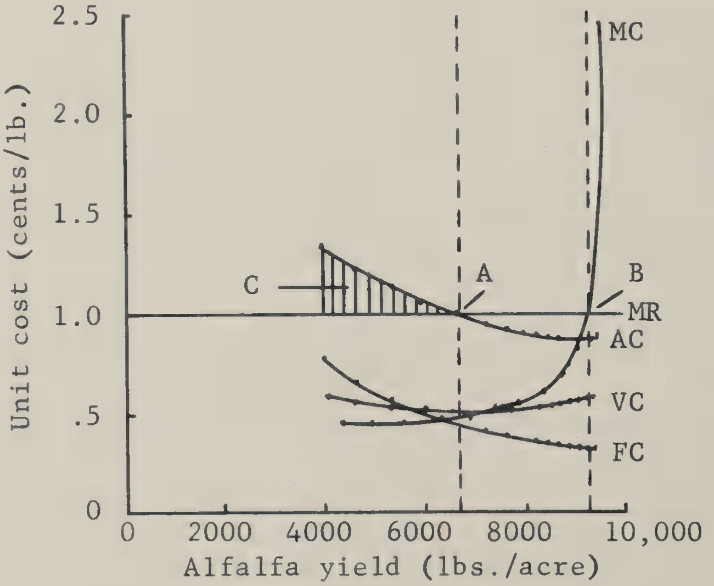


Figure 12. Relationship of levels of production to various cost and return curves to determine point of optimum production, Sevier Valley, 1962.

Table 30. Alfalfa yield and cost relationship per acre, Sevier Valley, 1962

Variable input (consumptive use in growing season) [a]	Alfalfa yield: Total output	Alfalfa yield: Marginal product of input	Alfalfa yield: Average output	Revenue: Total	Revenue: Marginal	Production costs: Fixed [b]	Production costs: Variable [c]	Production costs: Marginal [d]	Production costs: Total	Net income [e]	Unit costs: Fixed	Unit costs: Variable	Unit costs: Average	Unit costs: Marginal	Marginal unit revenue
In./ac.	Lb.	Lb.	Lb.	Dol.	Dol.	Dol.	Dol.	Dol.	Dol.	Dol.	Ct.	Ct.	Ct.	Ct.	Ct.
12	3,960		330	39.60		30.35	23.11		53.46	-13.86	.776	.584	1.350		
		640			6.40			3.01						.470	1.00
13	4,600		354	46.00		30.35	26.12		56.47	-10.47	.660	.568	1.228		
		725			7.25			3.32						.458	1.00
14	5,325		380	53.25		30.35	29.44		59.79	-6.54	.570	.553	1.123		
		675			6.75			3.11						.461	1.00
15	6,000		400	60.00		30.35	32.55		62.90	-2.90	.506	.543	1.049		
		620			6.20			2.93						.473	1.00
16	6,620		414	66.20		30.35	35.48		65.83	.37	.458	.536	.994		
		560			5.60			2.73						.488	1.00
17	7,180		422	71.80		30.35	38.21		68.56	3.24	.423	.532	.955		
		500			5.00			2.52						.504	1.00
18	7,680		427	76.80		30.35	40.73		71.08	5.72	.395	.530	.925		
		420			4.20			2.23						.531	1.00
19	8,100		426	81.00		30.35	42.96		73.31	7.69	.375	.530	.905		
		345			3.45			1.96						.568	1.00
20	8,445		422	84.45		30.35	44.92		75.27	9.18	.359	.532	.891		
		285			2.85			1.74						.611	1.00
21	8,730		416	87.30		30.35	46.66		77.01	10.29	.348	.534	.882		
		220			2.20			1.52						.691	1.00
22	8,950		407	89.50		30.35	48.18		78.53	10.97	.339	.538	.877		
		170			1.70			1.29						.759	1.00
23	9,120		397	91.20		30.35	49.47		79.82	11.38	.333	.542	.875		
		120			1.20			.97						.808	1.00
24	9,240		385	92.40		30.35	50.44		80.79	11.61	.328	.546	.874		
		60			.60			.64						1.067	1.00
25	9,300		372	93.00		30.35	51.08		81.43	11.57	.326	.549	.875		
		20			.20			.49						2.450	1.00
26	9,320		358	93.20		30.35	51.57		81.92	11.28	.325	.553	.878		
		-100			-1.00			.08						f	1.00
27	9,220		341	92.20		30.35	51.65		82.00	10.20	.329	.560	.889		
		-140			-1.40			-.06						f	1.00
28	9,080		324	90.80		30.35	51.59		81.94	8.86	.334	.568	.902		

a Data on physical productivity was taken from model 26.
b Fixed costs include interest, fertilizer, spraying, taxes, stand establishment, etc,
c Variable costs include ditching, irrigating labor, water cost, and harvesting costs.
d Marginal costs include all variable costs associated with the use of one unit of the variable water input.
e Net income is defined as the return to management.
f No valid basis for comparison.

SUMMARY AND CONCLUSIONS

Economists as well as farmers have encountered difficulties in determining the value of irrigation water. These problems have arisen because of inadequate data and procedures for handling complex relationships that affect crop yields. A need exists to identify the different factors that affect water-yield relationships at the farm level. The problems center around the many variable factors that influence water use and crop yields. Alfalfa was selected as a crop and the Sevier Valley as an area for concentrated study of these problems.

The primary objective of this study was to establish a production function for alfalfa with water as a variable input in the Sevier Valley using farm survey data. A secondary objective was to point out the analytical difficulties in establishing such a production function for alfalfa.

A multiple regression model using 12 linear, 12 nonlinear, and 7 interaction terms was employed in the study. The model included 3 physical, 3 nonwater management, and 6 water management factors and their associated terms. A coefficient of determination of .70 was obtained for the model. Intercorrelation problems associated with the model limit its usefulness for economic and predictive purposes. The predictive value of the model can be greatly increased by reducing the number of correlated variables. The reduction in the number of variables also reduces the coefficient of determination. Study results indicate that additional research on the correlation structure associated with

multiple regression models is necessary. The effects of interaction terms on the overall model should be part of this study. Correlation problems develop when more than one variable with similar functional relationships are included in the model.

Some of the problems within the model are associated with the data included in the analysis. The data used for year alfalfa in rotation should be for the age of the alfalfa stand on each field. Information on fertilizer application was for the survey year only. Data should be collected to include fertilizer applications for at least two years prior to the survey. These data were not available for this study. It is felt that the analysis would have been much better with these data.

Collection of information on irrigation water use was a major problem in the study. Twenty-six percent of the farmers surveyed were unable to provide necessary information on irrigation water use. Lack of knowledge on size of irrigation streams was the primary reason for this problem. The collection of presurvey data from irrigation companies could help to correct this shortcoming. Data on distribution within the season and the amount of irrigation water per irrigated acre also could be collected from the companies. These data could be used to assure that season distribution and irrigation water use per acre are given proper consideration in stratifying the survey population to obtain observations over the entire range of the production surface.

Study results indicate that optimum moisture days and actual consumptive use of moisture are better measures of water use than gross amounts of irrigation water applied. The information necessary for calculating these indicators are available from farm survey data and

engineering studies. The use of these indicators reduces the number of problems associated with timing of water application and availability of water to plants. Their use would increase the reliability and significance of the evaluation of increments of irrigation water.

Assuming the predicted values for consumptive use of moisture are correct, in spite of the intercorrelation problems in the model, the optimum use of irrigation water on alfalfa in the Sevier Valley is 40 inches per acre. At this use the net income to the farmer is $11.61 per acre. This assumes average conditions within the area except for 3 years alfalfa in rotation.

A more detailed cooperative study between agronomists, economists, and engineers is suggested for additional research. The study should include the use of both experimental plots and farm survey data on alternative uses of water. A linear programming approach could be used to optimize irrigation water use.

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Table 31. Basic data used in analysis by individual observations

Farm number	Alfalfa yield	Soil surface texture	Subsoil permeability	Slope	Fertilizer use	Total growing days	Years in rotation	Irrigations	Date of first irrigation	Days between first and last irrigation	Nongrowing season water	Water in growing season	Optimum moisture days	Consumptive use in growing season
	Tons/ac.	No. [a]	No. [b]	Pct.	Lbs./ac.	No.	No.	No.	No. [c]	No.	Ac.ft./ac.	Ac.ft./ac.	No.	In./ac.
1	2.50	2	3	2	0	106	8	3	135	40	0	1.50	64	18.1
2	2.00	3	3	1	36	142	8	2	135	66	0	.84	44	20.1
5	3.00	1	1	1	68	101	7	4	130	63	0	2.64	101	24.1
7	4.00	3	3	3	0	137	10	3	145	77	0	1.50	88	26.4
8	1.00	3	3	3	0	81	20	6	91	55	4.58	9.52	52	11.0
12	5.00	2	2	1	0	137	11	5	118	99	.79	3.16	129	25.7
13	3.00	2	2	1	60	132	5	6	140	95	0	3.99	107	24.6
15	6.00	2	2	2	0	137	6	5	91	83	.83	1.25	90	19.9
16	2.50	2	2	1	0	101	5	5	110	80	.53	2.11	97	22.0
17	5.00	2	2	1	0	142	7	3	140	108	0	2.49	94	23.9
20	4.00	2	2	2	0	137	5	4	130	92	0	2.25	115	25.7
21	4.00	3	3	1	0	137	9	3	105	102	1.13	2.26	97	24.0
23	3.50	3	3	1	45	132	5	7	125	92	0	2.10	126	25.2
24	6.00	2	2	1	0	147	8	4	121	101	0	1.72	128	27.0
25	4.00	2	3	2	135	85	5	6	91	149	.43	.87	85	15.8
27	5.00	2	2	2	0	132	5	5	110	101	.99	3.02	121	25.2
29	3.00	2	2	1	0	153	4	5	121	81	0	2.03	112	25.2
30	6.25	3	3	2	90	123	5	3	115	111	.80	1.60	100	19.7
32	5.00	4	3	1	0	111	5	4	100	127	.72	2.16	84	21.2
33	5.00	2	2	1	0	147	5	6	125	128	0	4.50	125	27.0
34	4.50	3	4	2	0	146	5	3	135	92	0	2.58	106	25.1
35	5.00	3	3	1	0	123	6	6	135	101	0	2.61	109	24.0
36	5.00	2	3	2	0	137	5	4	135	102	0	2.80	116	23.7
37	6.00	2	3	2	90	132	5	3	135	109	0	3.00	82	19.9
38	4.00	2	2	0	0	137	5	3	145	82	0	1.32	97	24.6
39	4.00	2	2	1	0	123	7	3	130	97	0	1.80	87	23.2
40	5.00	2	3	1	0	123	4	4	110	112	.50	1.50	107	24.0
41	3.00	3	3	3	0	137	8	3	135	52	0	1.84	73	19.8
42	5.00	3	3	1	135	153	7	6	135	160	0	3.50	139	27.9
43	5.00	2	2	0	60	123	6	3	121	107	0	1.41	94	22.3
45	5.00	2	2	2	56	152	5	11	105	149	.66	6.57	152	27.7
48	3.00	4	3	6	0	132	5	5	115	107	.30	1.20	72	24.7
49	5.00	2	2	1	45	137	4	6	105	117	.60	2.98	137	25.7
51	4.50	3	3	1	0	153	5	7	60	152	.89	5.31	121	26.1
52	5.00	2	2	1	45	137	4	6	120	102	.40	2.40	133	25.8
53	5.00	2	2	1	0	132	3	4	135	66	0	1.45	102	24.8
54	6.00	3	3	3	45	137	8	5	105	131	.42	1.71	121	25.8
55	3.75	3	2	4	45	137	6	5	91	169	.76	2.10	100	25.7

Table 31. Basic data used in analysis by individual observations - Continued

Farm number	Alfalfa yield	Soil surface texture	Subsoil permeability	Slope	Fertilizer use	Total growing days	Years in rotation	Irrigations	Date of first irrigation	Days between first and last irrigation	Nongrowing season water	Water in growing season	Optimum moisture days	Consumptive use in growing season
	Tons/ac.	No. [a]	No. [b]	Pct.	Lbs./ac.	No.	No.	No.	No. [c]	No.	Ac.ft./ac.	Ac.ft./ac.	No.	In./ac.
56	5.00	3	3	1	90	137	6	4	130	83	0	4.00	101	25.8
58	5.00	2	2	1	45	132	5	3	130	61	0	2.64	85	22.4
59	6.00	2	2	1	30	125	7	6	115	107	.53	4.19	125	23.0
60	5.00	3	2	1	0	147	5	3	130	92	0	1.80	97	24.8
61	5.00	2	2	2	0	132	8	3	125	87	0	1.02	91	27.9
62	4.00	3	3	2	90	123	7	2	67	99	.44	.44	67	17.0
63	4.00	2	3	1	0	132	4	4	115	86	.56	1.70	111	24.9
64	5.50	3	3	2	0	123	5	4	135	87	0	1.48	109	24.0
65	4.20	2	2	1	56	137	5	4	95	76	1.48	1.48	86	21.1
66	3.50	2	3	1	72	137	8	6	135	107	0	1.83	123	25.7
67	3.00	2	2	1	0	153	6	4	91	167	1.00	3.00	116	27.9
68	2.00	3	3	2	0	123	10	2	105	40	1.08	1.08	56	12.0
69	4.00	3	3	2	72	92	6	2	121	45	0	1.58	42	15.5
70	2.50	3	3	4	0	127	5	4	105	78	1.67	1.65	67	14.7
71	5.00	3	4	2	0	132	9	5	125	94	0	2.75	116	24.7
72	3.00	2	2	1	32	142	4	6	121	101	0	3.00	140	26.4
74	4.00	2	2	1	56	137	3	7	105	110	1.10	2.23	137	24.8
75	6.00	3	3	3	0	153	5	4	137	124	0	3.23	87	24.0
76	5.00	2	2	1	0	137	5	5	135	86	0	1.67	123	25.8
77	3.00	3	2	2	45	153	4	2	130	87	0	.86	67	19.5
78	5.00	2	2	1	68	123	5	3	130	85	0	1.80	96	23.5
80	4.00	2	2	1	0	137	10	4	121	117	0	2.40	115	23.1
81	4.50	3	3	1	0	137	4	8	84	138	2.07	3.45	122	25.8
82	5.00	2	2	2	90	147	5	4	156	138	0	2.40	91	24.6
83	3.50	3	3	1	63	127	6	6	105	86	.50	2.50	99	21.4
84	3.50	2	3	1	0	152	6	5	104	122	1.00	4.00	147	27.7
85	4.50	3	3	3	0	147	4	4	115	90	.65	1.95	102	22.5
87	4.50	2	2	1	0	137	4	6	105	136	.79	3.37	135	25.8
88	5.00	3	3	1	0	137	5	6	74	111	.83	1.65	91	20.1
89	4.00	3	3	1	113	137	10	5	135	90	0	.85	107	25.7
91	6.00	3	3	1	10	137	6	7	105	244	.50	1.50	116	23.3
92	5.00	3	3	3	15	123	8	7	91	122	1.00	2.50	109	24.2
93	3.00	2	3	1	0	137	4	3	145	35	0	1.15	92	22.8
95	4.00	2	3	2	0	137	5	6	95	129	.33	1.66	126	26.6
96	4.00	2	2	1	10	137	10	6	130	90	0	5.28	121	25.8
97	5.00	2	2	1	0	132	5	4	105	101	.75	2.25	115	24.4
98	5.00	2	2	1	0	142	4	3	130	111	0	2.25	101	28.3
100	3.00	3	3	1	0	123	6	3	145	36	0	1.14	59	19.7

a. Soil surface texture represented numerically with the following code: (1) fine, (2) moderately fine, (3) medium, (4) moderately coarse, and (5) coarse.

b Soil permeability represented numerically with the following code: (1) very slowly, (2) slowly, (3) moderately, (4) rapidly, and (5) very rapidly.

c Date of the first irrigation is shown numerically by the number the day falls in the year.